ECOLOGICAL STUDIES ON PERCOLATING FILTERS AND STREAM RIFFLES ASSOCIATED WITH THE DISPOSAL OF DOMESTIC AND INDUSTRIAL WASTES

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by

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Summary

The literature concerning stream riffle, percolating filter and invertebrate toxicity studies was is reviewed.

The film, micro-organisms and grazer populations were investigated at two sewage treatment works, one of which, Gospel End, treated domestic sewage and the other, Roundhill, a mixed domestic and industrial sewage. Extensive film accumulation at Roundhill, caused by high-frequency dosing, was unfavourable to extensive protozoan and grazer colonization. At Gospel End, where dosing frequency was variable, protozoan, nematode and grazer populations prevented film accumulation. Chironomids were more important in restricting film growth during the warmer months and pychodids during the winter. The density of the microfauna was also affected by the activities of the grazers. Twice as many protozoan species were found at Gospel End as at Roundhill.

The benthic fauna of the River Stour and its tributaries was investigated over a period of six years. The River Stour was found to be polluted by organic and toxic pollutants throughout the stretch from Halesowen downstream. Tributaries draining the south of the area were generally clean, whereas most of those draining the industrialised northern parts were usually badly polluted. Tubificids, enchytraeids and <u>Limnaea pereger</u> were the most abundant species found in organically polluted waters. In streams subject to discharges containing heavy metals, tubificids, enchytraeids and sometimes chironomids and <u>Asellus</u> were the commonest species. Improvement of the effluents from the two works studied led to improvements in the receiving watercourses. The Chandler Score was found to be the most applicable of the biotic indices considered.

In toxicity tests, *Asellus aquaticus* was the most tolerant of the test species to zinc at different temperatures, hardness and dissolved oxygen values. When dissolved oxygen concentration was high, *Baetis rhodani* was more tolerant than either *Gammarus pulex* or *Limnaea pereger*. *Limnaea* was generally intolerant to zinc.

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CONTENTS

VOLUME 2.

1. Introduction - review of percolating filter, stream riffle and toxicity studies

1.1. Percolating filter studies

1.1.1. Colonization

The colonization of a percolating filter is determined to a large extent by the availability of microfauna and grazers. Probably not all organisms found in the incoming sewage are able to colonize a filter for a number of reasons. The physical attributes such as the media, or the amount of the film or the flushing action of the jets might render the filter habitat inhospitable. Alternatively, the chemical nature of the applied waste might also prove unfavourable, either because of its toxic nature or its unsuitability as a food source. A comparable natural habitat is probably a mud-flat and this has been studied by Crisp and Lloyd (1954), who found that very few organisms found in a mud-flat had successfully colonized percolating filters. In fact from the dozen families of insects they discovered, only some half a dozen species are regularly found in filters. Reynoldson (1948) drew attention to the similarity between a filter and the wrack zone of the seashore and mentioned the work of Backlund (1945) who found that, with the exception of the chironomids, all the important filter species, especially *Lumbricillus lineatus* and *Enchytraeus albidus*, were found in the wrack zone.

Comparable in what way?

I believe this to be too sweeping

L. rivalis

This is not an important filter bed species.

The microfauna of a percolating filter is derived from soil or freshwater habitats and reaches a filter via the incoming sewage, either in the form of eggs or resting stages, or as adults. The macrofauna may be introduced with the sewage either at the egg stage, as could be the case of worms, insects or spiders, or as an adult e.g. worms, or as the larval or pupal stage of insects. Alternatively, insects can colonize a filter at the winged stage from a natural habitat or form another filter. Solbé et al (1967), studying an experimental filter, started observations of the fauna six months after the filter commenced operation. They found Psychoda larvae present in large numbers at this six month initial observation. Enchytraeid worms, although present, were not found in appreciable numbers until ten months after the start of the experiment. Lumbricid worms remained few in number until nearly two years had elapsed and their numbers increased only with the decline in the Psychoda and enchytraeid worm populations. They also found that some smaller invertebrates, such as copepods, rhabdocoels and aelosomatid worms appeared in the filter but did not become established. No work seems to have been published on the sequence of colonization by micro-organisms. Since micro-organisms are a source of food for some of the higher organisms, the establishment of a microfauna is of considerable interest in the study of colonization.

1.1.2. Succession and Maturation

As suggested in the previous section there seems to be a sequence of colonization of a filter by a fairly restricted group of species. Nevertheless, this colonization of a new habitat follows the same principals as those pertaining to any natural habitat, in that there is a change or succession in the populations until a stable climax community has been established suited to the particular habitat conditions, in this case the degradation of waste water in a filter. In a percolating filter a community is considered mature when a balance has been achieved between the film and the grazing fauna (Hawkes, 1963b). Ideally, therefore, when starting operation of a filter, due consideration should be taken of the colonizing and maturation capabilities of the fauna. This has been done in some cases, when a new filter has been treated with a culture of organisms or with effluent from an operating filter. Even then a grazing fauna should be allowed to establish itself before the full design flow is used. This can be done by operating the filter at low flows or with a low organic loading, so that there is not an excessive accumulation of film to prevent rapid colonization and maturation.

Even when a filter is considered mature it is still subject to change brought about by seasonal variations in temperature or by fluctuations in the organic or hydraulic loading (Hawkes, 1963b). These variations are reflected by changes in the extent of film and by the abundance and distribution of fauna. A study of the film and fauna at different depths in the filter often shows signs of vertical stratification according to the time of year (Solbé <u>et al</u> 1967;

Hawkes, 1963b; Hawkes and Shepherd 1971, 1972).

There has been some controversy about the optimum thickness of film desirable for maximum filter efficiency, whether it should be as thick as possible without inducing ponding or whether it should be barely perceptible. A series of experiments was carried out by Tomlinson and Snaddon (1966), to try to determine the critical thickness of film compatible with oxygen diffusion and filter efficiency. These involved rotating-tubes through which supernatant liquor from settled sewage flowed. A layer of bacterial film formed on the inner surface. Heterotrophic bacteria grew in the upper sections of the tube and nitrifying bacteria in the lower sections. One of these lower sections was exchanged after some time with a higher section and the supply of sewage was resumed. Heterotrophic bacteria grew over the nitrifiers and the depth this layer of heterotrophs attained before nitrite production stopped, as a result of a lack of diffused oxygen to the nitrifying bacteria, was taken as the critical depth of film growth. This depth was found to be 0.2 mm, but could be greater at higher oxygen concentrations. As the film increased in thickness the endogenous consumption of oxygen became relatively more important.

Maier (1968) in studies on the uptake of glucose and minerals by a biologically-active slime found, that the top surface of the slime was active in purification and that no significant effect on glucose removal was achieved by increasing the slime thickness beyond 0.04 cm. (Hawkes 1963b) quoted that Wuhrmann calculated the critical depth at which all the bacteria would receive an adequate oxygen supply as 0.1-0.2 mm, and that Gloyna et.al. found that a film thickness of 0.12 mm. brought about maximum efficiency. Later work at the Water Pollution Research Laboratory (W.P.R., 1971) concluded that a film thickness of less than 1 mm. was necessary for maximum efficiency. This low critical thickness emphasised the need for having as large a surface area as possible of filter medium exposed to the waste liquid. Accumulation of film reduces this surface area by filling the interstices and, as a consequence, impairs the efficiency of the filter.

1.1.3. Factors influencing the degree of film growth

The degree of growth and vertical distribution of the film is governed by a number of factors; namely, the organic loading, the rate and mode of application, the frequency of dosing, the degree of aeration, the temperature of the feed, the type and size of medium and the grazing activity of the fauna.

The organic loading or the BOD concentration of the filter feed can have a direct influence on the degree of film accumulation. The rate at which this BOD loading can be reduced will depend on the oxidative capacity of the microbial film and also the hydraulic loading. As Wheatland and Bruce (1970) have stated, the proportion of BOD removed decreases with increases in hydraulic loading. A high hydraulic loading is usually applied to filters containing either plastic or coarse mineral media, where the scouring action of the feed restricts the film and where only partial treatment is required. This type of operation is common in America (Hawkes, 1963b). At most British works, the hydraulic loading is such that only already loosened material is flushed out (Wheatland and Bruce, 1970) and so they are dependent on other agencies to prevent film accumulation.

One of these agencies is recirculation. This involves an increase in hydraulic loading but it also results in a reduction in the strength of the feed. This is achieved by recirculating either humus tank or filter effluent and mixing it with the filter feed to reduce the strength of the feed. The reported effects of recirculation are to reduce film growth in the upper layers because of the higher hydraulic loading and to bring about a more even vertical distribution of the film. (Hawkes, 1963b).

Another method of reducing film growth is by alternate double filtration (ADF). This involves the use of two identical filters with or without a settlement stage between. Tomlinson and Hall (1953) found that when settlement of primary effluent was omitted the quality of the final humus tank effluent was only slightly reduced. The primary filter receives settled sewage and the secondary filter receives settled or unsettled effluent from the primary filter. After a day or up to a week or more the order of the filters is reversed. The secondary filter receives a feed with a weak BOD loading and so the film growth goes into a negative phase (Hawkes, 1963b). When the primary filter shows signs of increased film growth the sequence of the filters is reversed. So not only does the method reduce film accumulation but also permits a BOD loading of up to three times that possible with single filtration (Wheatland and Bruce, 1970). If purification is not almost completed by the primary filter, the higher organic loading to the secondary filter will result in film accumulation in both filters.

The mode of application can have a marked influence on the effect of hydraulic loading. Hawkes (1959) investigated the effects on film accumulation by using different types of distributor jet nozzles. Fish-tail nozzles gave the greatest scouring action but suppressed the grazing fauna; splash plates gave an even distribution but tended to restrict the grazers mainly to Sylvicola (Anisopus); split jets, although resulting in alternate wet and dry zones, allowed the development of a mixed fauna, which was better able to restrict film growth.

The frequency with which the feed is applied to each part of the surface of the filter can drastically affect the growth of film. In a number of experiments (Hawkes, 1963b; Hawkes and Shepherd, 1971, 1972) it was found, that a low frequency of dosing considerably reduced film accumulation at the surface, especially in winter, that the vertical distribution of film was more even, that populations of fly larvae were greatly reduced, but that the worm populations were not adversely affected. High-frequency dosing resulted in extensive surface film accumulation and larger populations of fly larvae. If the jets are too close together or not staggered between the distributor arms, however, the effect is not so marked (Tomlinson and Hall, 1955).

Being an aerobic system an adequate supply of oxygen at all times is vital. The growth of filter organisms will be limited if the availability of oxygen is restricted. Aeration is often provided by air currents through the filter caused by differential temperatures found within and outside of the filter. In some filters ventillation shafts are installed, but many filters depend upon maintaining adequate voids between the media to preserve the aerobic conditions brought about by draughts through the underdrains. The reduced activity of the grazing fauna in the winter, leading to greater film accumulation which, if extensive, sometimes results in ponding, inevitably brings about reduced ventilation. This further reduces the activity of the fauna, ponding becomes worse and anaerobic conditions ensue.

The size and type of medium can be a critical factor in the occurrence of film accumulation and, therefore, of filter efficiency. A small medium has a relatively greater surface area but smaller interstitial spaces. "The optimum size of medium is thus the smallest on which the maximum degree of film accumulation...

can be accomodated without interfering with the ventilation of the bed or the even distribution of the waste" (Hawkes, 1963b). Although a large medium is better able to accommodate the accumulation of film, a smaller medium provides greater efficiency and, with judicious operation, can be prevented from being overgrown with film. Hawkes and Jenkins (1955) investigated the performance of four grades of media in relation to film accumulation and performance. They found that the smallest medium, with its theoretically relatively longer retention period, produced the best effluent, but showed the greatest degree of film accumulation. Truesdale and Eden (1963) used a neutron-scattering technique to measure the percentage saturation of voids, i.e. the amount of film growth in experimental filters containing different sizes of media in each, and found considerable accumulations of film in filters containing small media. Plastic media, which have a high proportion of voids, have been used for the partial treatment of strongly polluted liquors, because of their lesser tendency to become clogged. (W.P.R. 1969).

As discussed above, the rate at which BOD is reduced depends to some extent on the oxidative capacity of the microfauna. This is dependent upon temperature, the degree of aeration and the strength of the feed. Up to certain specific maxima the metabolic activity of the microfauna species increase with rises in temperature. It follows, therefore, that this activity will be greater in the summer than in the winter, and so the reduced activity during the colder months will allow greater film accumulation in winter. Probably, there are also interspecific differences in the capacity of the constituent species of the microfauna to break down different wastes.

The macrofauna of percolating filters is confined almost entirely to the Oligochaeta and Insecta though spiders, snails and *Asellus* have also been found. Their activity in helping to prevent film accumulation is fundamental to filter operation in Britain. Hawkes (1963) advocated encouraging maximum rate of film growth coupled with a dominant grazing fauna to check film accumulation.

The more equable temperatures, the reduced degree of competition and the usually ample food supply found in a filter enable the established species to thrive. Their role in reducing film growth has been the subject of a number of papers. Reynoldson (1939) stressed the importance of the enchytraeid worm, *Lumbricillus lineatus* (actually rivalis), in reducing surface growths of the blue-green alga *Phormidium* and the accumulated solids deeper in the filter. Lloyd (1945) stated, that the larger worms were of great importance in loosening solids within a filter, and Terry (1951) emphasised their value in reducing accumulations of film at times when the activity of insect larvae had decreased. The comparative effect, in experimental filters containing only *Lumbricillus rivalis* or only *Psychoda alternata* larvae or a mixed population of both, on the performance of filters was studied by Williams and Taylor (1968). They found that, compared with the control containing no animals, the BOD of all the experimental filters and the amount of film present was considerably reduced. Greatest film reduction was achived in the worms only filter and slightly less in the *Lumbricillus/Psychoda* filter.

macro-invertebrates

Hawkes (1965a), having frequently witnessed the grazing activity of *Psychoda* larvae in a filter treating domestic sewage, attributed the process of film unloading to *Psychoda* in the upper layers and probably to lumbricid worms in the lower layers. In experimental culture chambers, Hawkes (1965b) observed *Anisopus (Sylvicola)* larvae devouring fungal mycelium at an impressive rate. Lloyd (1945) suggested that the correlation between the flights of *Psychoda* and the elevated discharges of solids in the filter effluent was due to the emergence of flies from pupae embedded in the solids. Hawkes (1963b) proposed that insects probably assist in the biochemical breakdown of the film, because of the nature of their excretory products.

ow does this cause an increase the solids discharged?

1.1.4. Factors determining the nature and extent of the fauna

Although the macrofauna is of undoubted importance in restricting film accumulation, the species and numbers of grazers are determined by a number of factors, one of which is the thickness of the film.

According to Satchell (1947), the natural habitat of *Psychoda* larvae is mud, dung or rotting vegetation. Their preference for, or survival in, filters with thick growths of film is to be expected therefore (Lloyd, 1945; Hawkes, 1963b). At Langley, Hawkes (1957) found that after winter, during which heavy film growths prevailed in the upper foot, Psychoda larvae were the first species to reappear and increase in number. Limnophyes (= Hydrobaenus = Spaniotoma) and Metriocnemus larvae, on the other hand, prefer a clean filter (Terry, 1956; Hawkes, 1963). Lumbricids are favoured by thick growths (Terry, 1951).

As discussed in 1.1.3. recirculation and A.D.F. can have an effect on film growth. The increased hydraulic loading and the decreased strength of feed can change the abundance of the filter species, e.g. by reducing the numbers of Psychoda and Hypogastrura (Achorutes) and thus, by reduced competition, increasing the numbers of lumbricillid worms (Lumb and Eastwood, 1958; Hawkes, 1961). By putting a 15 cm. layer of large media at the surface of the filter and continuously wetting it by means of recirculation, den Otter (1966) claimed that the nuisance caused by Psychoda adults could be controlled.

Several workers have studied the effect of the nature and size of the medium on the grazing fauna. Terry (1951) found that lumbricid worms were much more abundant in small media, partly because of the abundance of food and partly in response to greater contact with the medium. In a later paper (Terry, 1956) he found that Psychoda severini and Hydrobaenus minimus were abundant in small media provided the sewage was weak and in large media when the sewage feed was strong.

Hawkes and Jenkins (1955) in their comparison of four grades of media found that in $1\frac{1}{2}$ in. gravel, whether round or crushed, *Psychoda*, *Anisopus* and *Lumbricillus* were successively dominant. In the largest medium ($2\frac{1}{2}$ in. round gravel) *Lumbricillus* was dominant and in the smallest medium ($1\frac{1}{4}$ in. cracked granite) *Lumbricillus* and *Psychoda* became very abundant. In contrast with the smooth gravel, a medium that is well pitted such as furnace slag or clinker, provides greater potentiality for colonization. Lloyd (1945) suggested that a rough, pitted medium rather than a smooth one was more suited to *Enchytraeus albidus* because of the lack of gripping power exhibited by its straight setae; *Lumbricillus lineatus* with its bifid setae is not thus inhibited. ?

In addition to these considerations, the medium should all be about the same size, apart from the bottom layer, otherwise there is a tendency towards consolidation with a consequent reduction in voids. Also, it should be of a non-friable material so that there is no breakdown into finer material, which too has the effect of reducing the size of the voids (Hawkes, 1963b).

s this part in relation to the fauna r to sewage purification?

Even provided with a suitable medium, filter fauna can still be restricted by the nature of the sewage. A waste containing a high proportion of industrial effluent can either prove toxic to all grazers or restrict them to a few species. The ill effects of such a waste can be lessened to some extent by pre-treatment or dilution. The nature of some wastes is such that fungi develop extensive growths which leads to ponding and thus represses the fauna. (Hawkes, 1965b). Lloyd

Surely the primary cause of a restricted fauna is the toxicity of the settled sewage — ponding is a secondary effect.

found that the strong chemical waste at Huddersfield enabled only the three species of *Psychoda* and *Spathiophora hydromyzina* to survive. The *Psychoda* species showed a range of tolerance with *Ps.alternata* the most resistant, then *Ps. cinerea* and *Ps. severini* the least resistant. Also at Huddersfield, Reynoldson (1948) found that *Lumbricillus lineatus* was replaced by the more resistant *Enchytracus albidus*. Hawkes (1963) stated that the commonest species found in filters treating Birmingham industrial wastes were *Psychoda alternata*, *Anisopus fenestralis* *Hypogastrura subviaticus*, *Lumbricillus lineatus* and *Spaniotoma minima* (*Lymnophyes minimus*). In filters treating mainly domestic sewage, the BOD loading is probably the most important factor as regards the waste.

L. rivalis
E. coronatus

Tomlinson and Hall (1950) found that the rate of application had an effect on the distribution of grazers. *Psychoda* larvae were the most abundant in filters operated at rates of 450-600 g.y.d; *Anisopus* larvae were more numerous in filters operated at rates of 100-450 g.y.d; *Hypogastrura* was not found in filters operating above 450 g.y.d., and *Lumbricillus lineatus* was not abundant in the filter operating at 600 g.y.d.

Where the jets have unmodified nozzles the fauna in the sub-jet zone is often different from that found in the inter-jet zone, at least at the surface (Hawkes, 1963b). Lumbricillid worms were most abundant below the jets and *Hypogastrura* and *Psychoda* in the inter-jet zone.

Low-frequency dosing has been used as a means of reducing film growth, but its effect on grazers is, therefore, also marked. Hawkes (1955) found that in low-frequency dosed filters *Anisopus* and *Psychoda* were severely reduced due to the restricted film growth and the greater downward flow of sewage within the filter. Lumbricillid worms, which were better able to withstand this flow, increased. A similar result was found by Hawkes and Shepherd (1970) in high- and low-frequency dosed filters. Enchytraeids remained similar in number in both beds, but the fly larvae were greatly reduced in the low frequency filter. Also, after reducing the frequency to the low-frequency regime, chironomid larvae became more abundant than *Psychoda* larvae, especially in the surface layer. An additional advantage of low-frequency dosing is the suppression of fly nuisance.

Perhaps they [illegible] better where there is [illegible] film

Lloyd (1943) discussed the effect of temperature on the abundance of *Psychoda alternata*. He recognised that sudden fluctuations in temperature could have an effect on fly emergence, resulting in a series of peaks, also that in warmer months, when the life-cycles were more rapid, larvae of the second cycle started life in a filter depleted of food. Golightly (1940) found that temperatures above 17°C had an adverse effect on the eggs of *Psychoda severini*, but not on those of *Ps. alternata*. The larvae of *Ps. severini* were favoured by low temperatures and *Ps. alternata* by higher ones. Reynoldson (1943) discovered that *Enchytraeus albidus* coronatus was not so adversely affected by a higher or lower temperatures as was *Lumbricillus lineatus*. Lloyd (1945) showed that *Metriocnemus*

I think not

rivalis

= hygropetricus

longitarsus and *Psychoda severini* could make better progress in the colder months than could their competitors, *Metriocnemus hirticollis* and *Ps. alternata*. The percentage of cocoons of the lumbricids *Dendrobaena rubida* and *Eiseniella tetraedra*, which successfully hatched, were found by Solbé (1971), to increase and decrease respectively with increasing temperature.

responses to temperature

The different thermal requirements of each species of grazer has led to seasonal patterns of vertical distribution. Solbé (1971), in his study of lumbricids, found that they were often absent from the top 60 cm. during early summer and in December, but were more abundant there from August to December. Other species tend to migrate from the surface during winter and return there during spring (Lloyd, 1945; Hawkes, 1963b).

Not strictly

Although they are micro-organisms, the rotifiers and nematodes are considered to be active grazers of the film. They have been largely overlooked and little work has been done on their importance. Peters (1939) listed a number of nematodes found in treatment plants. Tomlinson and Snaddon (1966) cited the possible role of nematodes in the breaking away of film and Hawkes (1963b) attributed the discharge of humus solids in experimental filters to the large numbers of nematodes found. Murad and Bazer (1970) found, that nematode populations increased with decreasing temperatures, though the temperatures recorded (in Louisiana, U.S.A.) were not as low as those experienced in a British winter. They also found that nematode numbers were almost completely reduced in humus tanks.

The role and distribution of Protozoa in percolating filters have been investigated by a number of workers. Cutler <u>et al</u> (1932) studying whether filters could be used to treat sugar-beet waste, constructed experimental filters and tested their ability to reduce a 0.2% solution of sucrose. Samples were taken to study distribution of Protozoa and it was found that <u>Arcella</u> and <u>Cinetochilum</u> preferred the lower levels of the filter, <u>Trepomonas</u>, <u>Colpidium</u> and <u>Bodo</u> preferred the upper layers and others such as <u>Paramecium</u> were found throughout. They attributed this distribution principally to food requirements, i.e. the availability of bacteria. Tomlinson (1941) in his initial study of ADF found that <u>Chilodon</u>, <u>Paramecium</u> and <u>Colpidium</u> the most frequent ciliates occurring near the surface, and <u>Litonotus</u> <u>Amphileptus</u>, <u>Aspidisca</u> <u>Euplotes</u> and <u>Oxytricha</u> at lower levels. Vorticellids were found throughout the filter. Flagellates and amoebae were more numerous in the upper layers. Barker (1942) found marked variations in the rhizopod, flagellate and ciliate populations in the colder months and in a later paper (Barker, 1946) showed that protozoan numbers are dominated in the summer by the activity of insect larvae and in the winter by temperature. He emphasised the role played by Protozoa in the flocculation of bacteria and also found that rhizopods and flagellates were most abundant near the surface of the filter, ciliates near the centre and <u>Conchulina</u> near the base. Tomlinson and Snaddon (1966) found a similar distribution in their rotating tubes and added that Opercularia was often abundant in the lower three of the four sections.

Williams and Taylor (1968) innoculated experimental filters with six species of Protozoa and found that, after a year, two of these had disappeared but that a further eight species had colonized the filters. Curds and Cockburn (1970) compared the Protozoa encountered in activated-sludge plants and percolating filters and found slightly different species and dominance by different species in the two processes.

Little work seems to have been done on the vertical distribution of bacteria, though it has been found that heterotrophic bacteria are more abundant in the upper layers and autotrophs lower down. This is as might be expected since the stronger, organically more complex liquid is found at the surface, where a range of heterotrophic bacteria, some of them quite specific in their substrate requirements, is capable of breaking down the waste into its simpler constituents. These constituents form a substrate for the more specific autotrophs, such as the nitrifying bacteria, lower down in the filter. James (1964) in investigating the slime found on filter media, discovered that the dominant bacteria were Gram-negative and rod-shaped which, he emphasized, resembled those found by Taylor (1942) in fresh water. He also found greater numbers of bacteria capable of growing at 22°C than at 37°C and that the maximum numbers of both were found at a depth of 9-12 in. Tomlinson and Snaddon (1966), using rotating tubes through which sewage was allowed to flow, found that zoogloeal bacteria were the first to appear, followed by fungal species. Brink (1968) found that the numbers of bacteria decreased most rapidly in the upper part of an experimental filter, where most of the organic decomposition took place.

Distribution of fungi seems to be determined by the chemical constituents or the rate of application of the feed and the physical attributes of the filter media. Tomlinson and Hall (1950) reported that in small-scale filters at Minworth growth of fungi was greatest in the top foot of the filters and when the rates of application were greater than 100 g.y.d. Tomlinson (1948) showed that fungal growth ceased when the BOD of the feed was reduced below 4 parts/100,000 (0.4 p.p.m.). <u>Sepedonium</u> sp. was found by Painter (1954) to require organic sources of nitrogen, whilst <u>Fusarium aqueductum</u>, <u>Geotrichum</u> sp. and <u>Trichosporon cutaneum</u> were capable of using ammonium salts. <u>Fusarium</u> and <u>Geotrichum</u> with their strong holdfasts are usually the first to colonize filter media (Hawkes, 1963b). The reasons for seasonal fluctuations in the extent of fungal growth were suggested by Hawkes (1965b) to be due to the joint effect of temperature, the nutrient strength of the sewage and competition with bacteria. The low temperatures and strong sewages of winter favour fungi and the high temperatures and weaker sewages of summer favour bacteria. Also the activity of the grazers, always greater in the summer, has a marked effect on the extent of fungal growth. Nutrient strength can be reduced by recirculation or where possible ADF which, suggested Tomlinson (1951), could be used as a means of reducing fungal growth.

1.2.1. Methods of sampling the film and grazing fauna of percolating filters

Until the investigations by Tomlinson (1941) and Reynoldson (1941) little work seems to have been done on investigating the fauna distributed throughout the depth of a filter. Reynoldson (1939) studied the fauna in the upper layers but not throughout the filter.

Tomlinson (1941), investigating the effects of ADF, inserted 12 in. diameter, perforated, earthenware pipes in three filters. Six baskets each 12 in. deep and filled with filter medium were placed in each pipe and removed at intervals to determine film and fauna. Reynoldson (1941) placed muslin bags filled with scalded alga in 3 in. diameter pipes, 12 in. and 36 in. in length, when studying a high-rate double filtration plant. After a period of time the food bags were removed and examined for organisms. In later experiments he inserted perforated zinc cylinders filled with media into the pipes on top of the bags. Tomlinson and Hall (1950) took samples at different depths in small-scale filters at the end of their experiments, when the filters were being dismantled. The filters were operated at different rates of application and the vertical distribution of the grazers, the fungus and the film was assessed. Hawkes (1955) placed perforated canisters, containing 0.1 ft^3 of medium, at different depths in filters down to 30 in., to study the effect of periodicity of dosing on the film and fauna. James (1964) used 1 in. concrete cubes at different depths in an experimental filter to study the distribution of bacteria and found maximum growth at a depth of 9-12 in.

Vertical shafts, containing perforated canisters, were inserted into a filter by Hawkes (1965b) to investigate the fungal growths occurring under conditions of ADF. Using this method, he studied the vertical distribution of fungal growth and film in shafts,with and without macroinvertebrates present. Solbé et al.(1967) used perforated metal shafts,containing perforated metal baskets filled with media,to study the colonization by macroinvertebrates of the top 5 ft. of an experimental filter. Sixteen shafts were used, three of which were sampled each month over a three year period. Hawkes and Shepherd (1972) used similar shafts and baskets to study the vertical distribution of film and fauna brought about by different dosing frequencies.

The problem of separating the film and fauna from the medium has been approached in a number of ways, but with the common factor of a quantity of washing water. Tomlinson (1941) used a metal vessel in the shape of a truncated cone containing an inner cylinder of perforated steel to which was fixed a vertical handle. The vessel was filled with water and the cylinder, containing the media and the attached film and fauna, was rotated. After running the water and its suspension out of the vessel, the water and residue were separated by decanting and siphoning. The separation of animals from film was performed by Tomlinson and Hall (1950) by removing the animals with dissecting needles and washing the residue on a gauze; the matter passing through the gauze was termed sludge.

Hawkes (1955) used a grid in a trough to wash the film and separate the animals, which were counted on a sectored, illuminated counting chamber. In a later paper (Hawkes 1965b) he described a revolving drum washing machine to remove the film from the medium.

After these preliminary stages, most of the workers later dried and volatized a portion of the film sample, to determine the amount of film. Others (Solbé _et al_, 1967) also did dry weight and volatile matter assessments of macroinvertebrates.

1.2.2. Methods for trapping emerging insects

A number of methods have been devised to trap insects emerging from percolating filters. Lloyd (1935) constructed a 1 ft.^{2} shallow wooden tray with a small hole in the centre over which a glass jar, containing an inverted paper cone, was placed. The tray was sunk into the surface of the filter. Reynoldson (1941), in addition to this tray, used an inverted tin can 4 in. deep sunk into the medium and changed both the can and the tray once a week for counting the trapped flies. An aluminium tray 1 ft.^{2}, 2.5 in. deep and divided into 16 equal squares was devised by Tomlinson (1947). The tray was placed face downwards on the filter surface and pressed about 1 in. into the medium. After 1-3 days the trap was lifted and placed on a lid, containing a chloroform tube to anaesthetise the flies.

Hawkes (1961b) used a Rothamsted suction trap to assess the density of _Anisopus fenestralis_ above filters.

The trap consisted of a gauze cone mounted under a suction fan. Flies drawn in by the action of the fan were collected hourly into tubes. An insect trap developed at the Water Pollution Research Laboratory was described by Solbé et al.(1967). It comprised a perspex and nylon-mesh box, fixed to a metal apron, which was set into the medium up to the top of the apron, so as to prevent lateral migration to and from the enclosed area by insect larvae and adults. Two inclined plates placed on top of the box and coated with adhesive trapped emerging insects. A central channel between the two plates distributed the sewage to the enclosed area of the filter.

1.3. Biological studies of stream pollution

1.3.1. Effects of pollution on stream riffle fauna

The study of the biological effects of pollution dates back to at least the beginning of the century, when Kolkwitz and Marsson (1908, 1909) introduced their 'Saprobiensystem'. This was developed as a means of assessing the effects of organic pollution, mainly on micro-organisms and plants. It has since been extended (Liebmann, 1951) to include macro-invertebrates, and will be discussed in more detail in 1.3.2.

A knowledge of the effects of various natural factors on riffle invertebrates is essential before an assessment can be made of the effects of polluting discharges. Amongst these natural factors, the most important are probably diurnal and seasonal temperature changes, current velocity, the nature of the substratum, the hardness of the water, the dissolved oxygen concentration and the extent of plant growth. Each species has a range of tolerance to each of these factors and drastic alteration to which can result in a reduction, if not elimination, of a particular species (Macan, 1963; Hynes, 1970; Odum, 1971).

The rate of natural alteration to the environment can be increased considerably by the effects of pollution, such as the increased amounts of suspended solids in a stream brought about by discharges of effluent from overloaded sewage treatment works, or by the decrease in dissolved oxygen concentration induced by the high Biochemical Oxygen Demand of an effluent, or an increase in temperature, as a result of electricity generating station cooling water entering the river (Hynes, 1960).

The nature of polluting discharges may be conveniently classified into 1. organic, 2. toxic and inorganic, though often they occur together and so their effects may be interdependent.

One of the first attempts to make carry out a biological survey to assess the effects of organic pollution on macroinvertebrates was that of Richardson (1928). He surveyed the middle Illinois River through the years 1913 to 1925, during which time over 1,300 samples were taken. Only *Limnodrilus hoffmeisteri* and *Chironomus plumosus* were considered by Richardson to be of any value as indicators of pollution when occurring by themselves. He proposed, what has since become generally accepted, that the absence or reduced numbers of formerly present clean-water species were just as indicative of pollution. He found that much of the pollution load was derived from cattle stockyards and increasing discharges from sewage works. Gastropoda, Sphaeriidae, Ephemeridae, Hirudinea, Hydropsychidae, Odonata, planarians and Amphipoda were the groups most seriously affected. There was a dramatic increase in the numbers of Sphaeriidae and later the predatory leeches, when the river improved.

Gross organic pollution usually results in depletion of the dissolved oxygen and a reduction or elimination of the normal riffle inhabitants. These are superceded by what Hawkes (1962) has called 'the replacement fauna', which comprise tolerant species, consisting at first of species such as Psychoda larvae and Eristalis larvae, both of which are air-breathers, (Hynes, 1960). At lower levels of organic enrichment, the development of sewage fungus may occur. This comprises mainly protozoans, bacteria and some fungi, but Naid worms also thrive and even Gammarus is known to survive there. (Butcher, 1955; Hynes, 1960).

As Richardson (1928) found, tubificids and chironomids are often found in vast numbers in organically polluted watercourses. This has been found also by other workers (Hawkes, 1956; Butcher, 1955; Learner et al, 1971). Brinkhurst (1965) found that in the River Derwent, Derbyshire, Tubifex tubifex, Limnodrilus hoffmeisteri and Nais elinguis were most tolerant of organic enrichment, but that as conditions improved T. tubifex became less abundant and other tubificids returned, so there would appear to be a gradient of tolerance to organic pollution within the Tubificidae.

The most frequently found chironomids in the grossly polluted zones seem to be Chironomus plumosus (Richardson, 1928, Hawkes, 1956) and C. riparius (Hynes, 1960) though according to Hynes (1960) they are not quite as tolerant as tubificids of very low concentrations of oxygen. These two species are succeeded downstream by the chironomids (Orthocladiinae and the carnivorous Tanypodinae (Hynes, 1960). It has been reported that by their action of respiratory ventilation, the chironomids increase the depth of the aerobic layer in silty deposits (Downing and Edwards, 1968).

A further improvement, often signified by the appearance of abundant growths of Cladophora, results in the return of more species to what has often been called 'the recovery zone'. Asellus aquaticus, Erpobdella testacea, E. octoculata, Limnaea pereger, Physa fontinalis, Sialis lutaria, Glossiphonia spp. Sphaerium spp. and Simulium ornatum have been found by many workers to colonize this zone, often in appreciable numbers, though not necessarily all of these species have been found occurring together (Richardson, 1928; Butcher, 1955; Hawkes, 1956; Hynes, 1960). Richardson (1928) found Asellus intermedius in what he called the sub-pollutional zone, but only where there was a fairly strong current. Other species found included Planaria and Hydropsyche spp., but the most successful re-colonizing group was the Sphaeriidae. Butcher (1955) found, in the recovery zone downstream of a serious discharge of gas liquor, that in succession Asellus, molluscs, leeches, Gammarus and *Hydropsyche* appeared. The extent of these different zones varies according to the pollution load. Richardson (1928) reported that the tubificid/chironomid zone stretched for over 50 miles in bad conditions. Hynes (1960) described the changes in the River Lee, Hertfordshire, where the *Chironomus* zone was quite extensive some years and at other times had disappeared. Similarly, Pentelow *et al.* (1938) found fluctuations in the extent of the *Chironomus* zone and the *Asellus* zone downstream of a milk waste effluent in the Bristol Avon.

With increasing self-purification the less tolerant animals, such as *Gammarus* and *Hydropsyche*, start to reappear in larger numbers. Butcher (1955) showed that this occurred in the River Trent and Hawkes (1963a) in Langley Brook, a tributary of the River Trent. The mayfly *Baetis rhodani* may also be included in this group, in fact Hynes (1960) found it more abundant than *Gammarus* in the Welsh Dee. Downstream of a weak organic discharge the effects might only be minimal. The resulting very mild pollution can still be detected biologically, however. Hynes (1960) showed that in the Dee a number of groups were affected by a mildly polluting discharge. Amphipoda, mayflies, stoneflies, caddisflies, beetles and *Ancylastrum* were slightly, adversely affected whilst the numbers of midges increased. At different distances downstream the adversely affected groups returned to their former prominence. *Simulium* species seem to be favoured by very mild organic pollution, such as that encountered downstream of a well-purified sewage works effluent, where there is an increased supply of bacteria. (Hawkes, 1962). Mann (1961) suggested that Erpobdella testacea was better able to withstand low oxygen levels than E. octoculata and Hynes (1960) found only E. testacea below the polluting outfall in his survey of the Dee. As it progresses downstream, providing there are no further serious discharges, the river becomes self-purified and there is a return of clean-water fauna (Hynes, 1960; Hawkes, 1962).

Having discussed some of the results of survey work on the effects of organic pollution, some of the causes of this type of pollution may now be described, though their effects rarely act alone.

One of the principal effects of organic pollution is de-oxygenation and some of the more obvious sources of discharges causing de-oxygenation are from sewage treatment works, food-processing factories, breweries and wood-pulping mills. Other substances or reactions which exert a biological oxygen demand (B.O.D.) include nitrification, sulphites, sulphur dioxide, ferrous salts etc. The micro-organisms which break down the organic substances require oxygen to do so and so there is a reduction in the amount of oxygen available to macro-invertbrates (Hawkes, 1962). This leads to the replacement of the fauna usually inhabiting riffles by animals such as tubificids and chironomids, which can tolerate low oxygen concentrations. Often there are outbreaks of sewage fungus. Edwards et al. (1972), in their survey of the Taff catchment, confirmed the suggestions of Hawkes (1962) and Curtis (1969) that the specific nature of the sewage fungus is influenced by flow. Sphaerotilus *natans* was dominant in the Taff where flow was above 50 cm/sec. and where dissolved oxygen concentrations were relatively high, whereas *Zooglea* was found where flows and dissolved oxygen were less.

Butcher (1955) found heavy growths of sewage fungus (*Sphaerotilus*) downstream of effluents from beet-sugar factories, creameries and food-processing factories along the River Trent, and Hawkes (1963a) noted the occurrence of sewage fungus in Langley Brook and the River Cole downstream of sewage works and sewer discharges. Hynes (1960) has shown graphically a sequence of growths and declines of various populations, accompanying de-oxygenation and re-oxygenation, proceeding downstream from an organic outfall, starting with sewage fungus, tubificids and chironomids and passing downstream to algae, *Asellus* and *Cladophora*.

Another factor causing oxygen demand is that of decaying weeds. Westlake (1959) has calculated that decaying weeds use up oxygen equivalent to amounts they have previously released during growth. Hynes (1959) indicated also that mine water and ground-water are often low in oxygen content and therefore exert an oxygen demand when issuing into streams.

The nitrification of ammonia by nitrifying bacteria to nitrites and nitrates also requires oxygen. Ammonia itself becomes more toxic as the oxygen content falls (Downing and Merkens, 1955) and is also more toxic in alkaline than acid waters (Hynes, 1960). *Chironomus thummi* (*C. riparius*) was found by Hynes (1960) to tolerate quite high concentrations of ammonia found in organic muds and silts. The effects of even mild pollution by ammonia can be detected by sampling riffle fauna. Hynes (1960) surveyed a river receiving an effluent containing very small amounts of ammonia and cyanide and reported that Polycelis, Esolus, Leuctra and Isoperla spp. were markedly affected just downstream of the outfall but recovered within a short distance. Amphinemura and Orthocladiinae were slightly reduced in numbers and caddis larvae, Ceratopogonidae and Tanypodinae were unaffected.

Solid matter suspended in the body of the water may be organic, inorganic or both. The immediate effect of an increase in suspended solids is to reduce the amount of light penetrating the water, which has a deleterious effect on the benthic algae and on animals such as fish which rely on sight for feeding (Hawkes, 1962). The organic solids found in sewage works effluents are either oxidised or in the process of oxidation by bacteria. Where the velocity of the current is reduced they tend to settle out and can blanket a riffle with sediment, resulting in an elimination or reduction of many benthic algae and the replacement of the indigenous fauna by silt-loving species or those tolerating low oxygen concentrations, such as worms and midge larvae (Hynes, 1960).

Hynes (1970) has described species typical of sandy substrata, which include some mayfly and stonefly species, but they do not seem to occur where there is too much organic matter. Learner et al. (1971), in their survey of the River Cynon, found a drastic change in the fauna, downstream of a coal-washery, from a very varied one to

Organic pollution was also present in the Cynon

one dominated by oligochaetes and chironomids. Similar effects of coal washings were found by Hynes (1960) near Liverpool, though in this case the effects were complicated by a pig-farm effluent. Edwards _et al._ (1972) found that _Gammarus pulex_, Ecdyonurids, Simulidae, _Hydropsyche instabilis_ and Chironominae were either restricted in the Taff catchment or poorly represented, because of the adverse effects of suspended coal particles.

Species of _Baetis_, _Centroptilum_ and _Perlodes_ were reduced or absent below a discharge of sand-pit washings to a Scottish stream (Hamilton, 1961), but _Nais_, _Stylaria_ and _Ephemerella_ ocrurred in greater numbers. Enchytraeidae, _Gammarus pulex_, several species of mayflies, caddisflies and chironomids, _Simulium_ and _Ancylus_ seemed to be unaffected. Nuttall (1972), however, in his study of the River Camel, found that where sand had been deposited _Baetis rhodani_, _Rithrogena semicolorata_ and tubificids were abundant, but that _Polycentropus kingi_, Simulidae, _Leuctra nigra_, _Ephemera danica_ and _Gammarus pulex_ were amongst those eliminated by sand deposition. In a survey to detect the effects of china-clay wastes on Cornish rivers, Herbert _et al._ (1961) discovered mayflies, stoneflies, caddisflies, chironomids and oligochaetes in both clean and china-clay-polluted streams, but _Gammarus_ was absent from some polluted stretches and gastropods and bivalves were not found in any rivers so affected.

Alabaster (1972), in a review, quoted an instance in France of Ephemeroptera, Trichoptera, Crustacea, Mollusca and worms being eliminated below the discharge of wash-water from a tin mine. Jones (1958) attributed the paucity of fauna in the River Ystwyth not only to the zinc in solution but also to the mining debris of the stream bed providing an inhospitable habitat for both invertebrates and their food, the benthic algae. He ascribed the scarcity of cased caddis in a tributary of the River Rheidol to the lack of plant material, brought about by the gritty mine-dump material deposited on the stream bed (Jones, 1940b). Weatherley et al. (1967) stated that the principle indirect effect of zinc pollution was the inducement of an unstable substratum by the toxic effect on the stabilizing plants. Heavy metals in solution, however, often have more serious effects on riffle fauna; these effects have been studied by a number of workers.

A considerable amount of work on the effects of heavy metals on stream fauna has originated in Wales, where studies on the fauna of streams polluted by lead and zinc have progressed over the past 50 years. Carpenter (1924) in her initial study of the fauna of the River Rheidol and River Ystwyth found, that the community was restricted to crustaceans and various species of insects including stoneflies and mayflies. The source of lead was the drainage from lead-mine tippings; lead was in solution in the river at concentrations of 0.2 to 0.5 mg/l. By 1922, this concentration had fallen to a maximum of 0.1 mg/l. and more species had appeared, especially trichopterans. The only plants which flourished were the algae Batrachospermum and Sacheria, but by 1922 some macrophytes had reappeared. A further survey in 1931-2 (Laurie and Jones, 1938) revealed that a considerable recovery had taken place; 17 species of caddisflies, 36 beetle species, 8 species of stoneflies, 4 species of mayflies, molluscs, oligochaetes and leeches had reappeared. Carpenter (1926) studied another river, the Teify, a year after a lead mine had re-opened and found that <u>Ancylus fluviatilis</u> and caddis larvae had disappeared.

Zinc sulphate, derived from the oxidation of zincblende in the lead-mine dumps, was found by Jones (1940a) to be in even greater concentrations than lead in the River Ystwyth. Normal concentrations of zinc were from 0.7 to 1.2 mg/l. In a half-hour search of a heavily polluted stream (nearly 60 mg/l. zinc) <u>Leuctra</u>, <u>Nemoura</u>, <u>Rithrogena</u> and <u>Velia</u> were the most commonly found species. In a tributary of the Rheidol, the Melindwr, where zinc concentration was up to 3 mg/l., Jones (1940b) established that some cased caddis were absent due to the lack of plant food, but that carnivorous caddis were present. In a later survey of the Ystwyth, Jones (1958) measured zinc concentrations between 0.2 and 0.7 mg/l. and found that <u>Rithrogena semicolorata</u>, <u>Heptagenia lateralis</u>, <u>Baetis rhodani</u>, <u>Chloroperla tripunctata</u> and <u>Esolus parallelopipedus</u> were the commonest species and that oligochaetes, leeches, molluscs and crustaceans were still absent. Weatherley <u>et al.</u> (1967) found that in an Australian river polluted with zinc, Plecoptera, Hemiptera and Arachnida were relatively immune, but emphasized the semi-aquatic existence of the latter two groups.

A biological survey of the River Trent and its tributaries revealed the existence of at least three sources of copper pollution (Butcher, 1955). A discharge of copper from a factory to the River Churnet brought about an elimination of all the fauna and much of the microflora. There was a return of some microflora within 5 miles, but even after joining a trout stream, the River Dove, no animals were found. Two discharges of copper to the River Rea in Birmingham exterminated all life as far as its confluence with the River Tame. In the River Tame itself, discharges of gas liquor produced a tubificid/Sphaerotilus community which was eliminated by a copper discharge, and tubificids did not appear again until 15 miles downstream. Doudoroff and Warren (1957) found that Physa was very sensitive to copper.

Little work seems to have been done on the biological effects of oil pollution in streams, probably because in most countries oil-refinery facilities are on coastal sites. Meynell (1973) studied the effects of discharges from an oil-refinery and petrochemical complex on the biology of a Spanish river. The wastes included oil, phenols, ammonia, hydrocarbons, etc. No macroinvertebrates were found for 43 km. downstream of the complex, the first species to reappear being Tabanus sp. and Ephydra sp. Further downstream, below a dammed lake, Ancylus fluviatilis and Simulium sp. were common and oligochaetes and chironomids were also found. Greater recovery was found at the next station downstream where Hydropsyche sp., Odonata, prawns and Dugesia lugubris occurred, some abundantly. McCauley(1965) reported that

/Dugesia

Gammarus and Agrion nymphs were intolerant to oil pollution, but Tubifex, Tendipes larvae, Nematoda and Hirudinea survived.

As Hawkes (1962) has indicated, opportunities for studying the direct effects of acid wastes on fauna are unavailable in Britain because of their association with toxic metal wastes. In South Africa, however, Harrison (1958) was able to study the effect of discharges to streams of sulphuric acid derived from coal and gold mining. One stream had a pH as low as 2.9 and it was found that in this stream and others like it only chironomids, a mite sp. and certain algae survived. Caddisflies, mayflies, beetles, Simulium and Orthocladiinae were eliminated. Similarly in Pennsylvania, Koryak et al. (1972), in their study of sulphuric acid drainage from coal mines, found that where the pH was 2.6 only midge larvae, especially Tendipes sp. flourished, though some Tipulidae larvae were found also. Amphipoda, Plecoptera, Ephemeroptera and Oligochaeta were missing. Gammarus, mosquito larvae and caddis larvae were found by Lackey (1938) in streams with pH values as low as 2.3, and Robeck (1965) recorded six genera of caddis larvae in water of pH 3.0.

Discharges of cooling water from electricity generating stations can have marked effects on the stream fauna. The main effects are augmentation of the rates of metabolism and of chemical reactions, and the effect on oxygen solubility. The reduced solubility of oxygen at higher temperatures is not wholly compensated by increased oxygen diffusion, so that pollution of a river often has more serious consequences in summer (Mercer, 1967). Gameson et al. (1959) found great diurnal variations in the temperature and oxygen concentration in the River Lee, which receives condenser water from a power station. The effects of increased water temperatures on stream fauna have been studied by a number of workers. Trembley (1962) reported, that the number of species was greatly reduced, but that the biomass of the remaining animals increased during winter. Midge larvae were the most tolerant invertebrates though Unio also was often abundant. Mann (1965) found that snails and mussels were favoured by warmer water in the River Thames but leeches, shrimps, and midge larvae were not. Studies on the metabolism showed that the breeding activity of benthic species from the River Thames was advanced, especially that of Asellus aquaticus. The temperature of the River Derwent was found by Butcher (1955) to be raised 10°C by power station condensing water. Despite the river being organically polluted, roach were attracted to the heated stretch during winter by the warmer temperatures and the abundant food supply.

The report by E.I.F.A.C. (1968), based largely on Slavonic literqture and research, indicated a general increase in the rate of development and in some cases (Daphnia sp.) in size; for example the embryonic development time of Daphnia cucullata was reduced by a 15°C temperature rise from 3.5 days to one day; tendiped larval development rate increased three-fold with a temperature rise from 15 to 25°C. There is a variation in the highest temperatures that different species can withstand. In the Thames, Mann (1965) maintained that the lethal temperature appeared to be between 32°C and 35°C for most species. The E.I.F.A.C. (1968) report stated that the lethal temperature for *Chironomus dorsalis* varied between 34°C and 37°C. By raising the acclimation temperature, Sprague (1963) found that the lethal temperature for *Asellus intermedius* and *Gammarus fasciatus* was 34.6°C; for *G. psendolimnaeus* it was 29.6°C and for *Hyalella azteca* 33.2°C. surprise surprise!

? As might be expected of the riffle fauna, insect larvae are the most affected by insecticides. Hynes (1961b) pointed out that a great abundance and diversity of worms compared with arthropods was a good indication of pollution by insecticides. Whitten and Goodnight (1966) found that DDT was non-toxic to worms at concentrations exceeding 100 mg/l. Much of the insecticide which is likely to affect riffle fauna enters the stream either directly as a result of aerial spraying or indirectly through run-off from land treated with insecticides. Webb (1960) and Graham (1960) have studied the effects on stream fauna after aerial spraying of forests with insecticides. Caddisflies, stoneflies, alder-flies, beetles and dipterans were seriously affected though chironomids and mayflies recovered rapidly and produced higher populations than normal. Snails, worms and water mites did not seem to be affected at all. Welch and Spindler (1964) reported, that after aerial spraying of DDT to control spruce-budworm all aquatic insects were killed and at some points there was no fauna at all. Tomlinson et al. (1949) found, that at concentrations of just below 0.02 mg/1. DDT, Chironomus larvae were not killed but were unable to build tubes.

Hynes and Roberts (1962) stated that the main effects of detergents are interference with oxygenation, foaming, and their wetting properties. Interference with oxygenation is only serious in sluggish reaches where the rate of re-aeration is low (Gameson *et al.*, 1955). The effect of foaming is probably minimal but increased wetting-ability could trouble emerging insects (Hynes and Roberts, 1962). In their survey of the River Lee, Hynes and Roberts (1962) reported, that detergent in effluent derived from Luton sewage treatment works, appeared to have had no adverse effect on the fauna of the river.

...e these effect?

1.3.2. Indices of stream pollution

The need to interpret the results of biological pollution studies and surveys has brought about the development of various indices of differing degrees of complexity. The Saprobiensystem of Kolkwitz and Marsson (1908, 1909) was the first scheme to be proposed as a means of classifying a water course according to its degree of pollution. It consisted primarily of lists of organisms associated with various degrees of recovery from organic pollution found in a large river and was divided into polysaprobic, alpha-mesosaprobic, beta-mesasaprobic and oligosaprobic zones, the oligosaprobic zone being the zone of completed oxidation. The lists consisted of mostly algae and microfauna, though this shortcoming was partially remedied later, by Kolkwitz (1950) and by Liebmann (1951), ~~to include the~~ by the inclusion of macroinvertebrates.

...ol the ...obiensystem

The original saprobiensystem relied on the presence of organisms, regardless of abundance, to indicate conditions, but the later revision by Liebmann (1951) emphasized the importance of abundance and of the community of organisms. However, as Hynes (1964) has indicated, Liebmann did not consider physical factors nor that the system applies only to organic pollution and that it does not distinguish between different types of organic pollution. Several workers have shown that the whole concept of the system is too rigid, that in fact many species have a range of tolerance to difference factors and could, therefore, be found in more than one of the saprobic zones (Fjerdingstad 1950, 1954; Gaufin and Tarzwell, 1956). Hynes (1960), in an assessment of the system, stated that in turbulent waters organic pollution does not produce the de-oxygenation typical of the polysaprobic zone and quoted the work of Swiss researchers (Steinmann and Surbeck, 1918) and American researchers (Gaufin and Tarzell, 1956) who gave examples of this phenomenon. It was also stressed by Hynes (1966) that upstream conditions determine the ecology of a particular zone, for example, the ecology of the mesosaphrobic zone is influenced by the existence or absence of a polysaprobic zone upstream.

However, the saprobiensystem has been equally vigorously supported, notably by Sladacek, and even extended into further zones by Thomas (1944), Sramek-Husek (1958) and Sladacek (1967). The latter conceded that there were limitations to the saprobiensystem in that it did not consider "toxic, radioactive and cryptosaprobic conditions" and expanded the system into thirteen degrees of saprobity. He emphasized that recently there have been ecological and physiological approaches to explain the theory of saprobity.

Hawkes (1956) used the Saprobiensystem as well as an assessment of abundance in his study of Birmingham streams and he also confined his stations to riffles. Both the nature of the micro-organisms found on the stones and the macroinvertebrates were included in the assessment. Using this method, it was possible to determine the source and to a large extent the nature of polluting discharges. The concept, such as that of the Saprobiensystem, of using certain organisms as indicators of pollution has proved attractive to a number of workers. Butcher (1947) described different zones in a river characterized by different algal communities and showed how these communities could indicate pollution and recovery. Patrick (1957) devised a diatometer to hold glass slides, upon which diatoms could grow, when immersed in a stream and she advocated the use of diatoms to indicate changes in conditions. The use of diatoms was proposed also by Round (1962), but he emphasized the need for more precise quantitative correlation between diatom flora and the habitat requirements. Brinkhurst (1962), whilst realising the ubiquitous distribution of Tubifex tubifex and Limnodrilus hoffmeisteri, emphasised their indicator value as the only species occurring in zones of gross organic pollution. Liebmann (1951) advocated the use of micro-organisms as indicators. The concept of indicator species, however, has been criticised by Hynes (1960) and Hawkes (1962). They stressed the facts that so-called indicator organisms occur also in unpolluted water and that they are not only adapted to living in polluted waters, which is a product of civilization, and so this has considerably reduced their value. In more recent years, macro-invertebrates have been used increasingly as the basis of biological assessment of pollution. Richardson (1928) was amongst the first to make use of maccroinvertebrates in pollution survey work, but although he found more than 27 species of benthic invertebrates in the pollution zone, only Limnodrilus hoffmeisteri and Chironomus plumosus encouraged even moderate confidence in their value as indicator organisms.

A complementary theory to that of the Saprobien-system or the indicator species concept is that of the absence of species from polluted streams. Patrick (1950) developed a method based on this theory, which involved the comparison of the species found in various groups in the study stream with numbers found in those groups in a comparable clean stream. The results were presented as histograms in which the heights of seven columns (groups) represented the numbers found as a percentage of the same groups found in clean conditions. Hynes (1960) considered this idea was based on dubious assumptions mainly because of the great variety of reactions to be found even within one group of species. A further development of this approach was shown by Wurtz (1955), who divided species into tolerant and non-tolerant to pollution.

Four modes of life, burrowing, sessile, foraging and pelagic, were represented by composite histograms for each station, with non-tolerant species placed above a base line and tolerant below it. The percentage shown by each group of the total number of species found at each station determined the height of each column. Hawkes (1962) objected to this method on the grounds that few species can be separated into tolerant and non-tolerant to pollution.

Beak (1965) created a biotic index which attempted to correlate feeding type with pollution tolerance. He classified the rather restricted community found at his stations, all of which had a silty substratum, into predators, herbivores, filter feeders and detritus feeders and further subdivided these into intolerant, facultative and tolerant to pollution. His findings were similar to those of other workers, namely a large number of species was found in clean water and a restricted number in polluted water. His proposed biotic index ranged from 0 to 6 according to increasing cleanliness. He thought that some value could be derived from the abundance of species showing definite reactions to changes in pollution intensity, such as that shown by different species of midge larvae. Also differential stress on species derived from different trophic levels resulted in increasing abundance of some species, usually those relieved of predation or competition.

Another index based on the presence and absence concept is the Trent Biotic Index (Woodiwiss, 1964). In this sytem animals are sorted into key groups according to an empirically derived tolerance to pollution. The index ranges from 0 to 10, 10 being very clean. The animals are not counted and so the differences in abundance of the different groups are not considered. Other drawbacks include the absence of molluscs as a key group and the total absence of taxa such as Enchytraeidae, Naididae and green chironomids, Graham (1965) adapted this system for use in the Lothians region, but on his scale the highest score, 6, represented gross pollution. Although Graham included snails, naid worms and midge larvae in key groups, the same drawbacks are apparent as in the Trent index. In both systems, the assumption that all the species in a particular group react in a similar way to pollution can lead to erroneous conclusions. Also, both systems are applicable only to organic pollution. A consideration, for example, of the tolerance of some? Plecoptera to toxic pollution (Jones, 1940b) would have placed this group in a different position.

Recognising some of these drawbacks, Chandler (1970) devised a system based on levels of abundance. These levels were applied to each taxa and given a score according to their order of tolerance to organic pollution. The score increased for species characteristic of clean water as their abundance increased and decreased for pollution-tolerant species as their abundance increased. Despite this allocation of a score relative to abundance, no account is taken of the significance of dominance, that is there is little difference between a score for 'present' and a score for 'very abundant', especially within the least tolerant species. Lumbricids, enchytraeids, and Tipulinae are not included and there is no differentiation shown between pulmonate and operculate snails. Also the working of this system can be time-consuming.

Sladacek (1973) maintained that the three British biotic indices, described above, were in essence based on the later developments of the Saprobiensystem, that they were indicative only of the tolerance of riffle macrofauna and that they were more subjective in their use than the Saprobiensystem was.

The unsatisfactory applicability of the above methods to conditions in South Africa, where there are considerable fluctuations in water flow and in the stability of river beds in the rainy season, has led Chutter (1972) to devise a biotic index applicable to these conditions. Only riffles were sampled and each taxon was allotted a quality value between 0 and 10, according to information, derived from the literature, on the type of water where the greatest abundance of each occurred. Species frequently found in polluted waters were valued 10 and those from clean streams 0. Because of the wide tolerance of some species their quality values were related to the Baetid Ephemeroptera. Large numbers of tolerant species did not indicate pollution when baetids were abundant and diverse, but a decrease in this abundance and diversity indicated poorer quality water and so the quality values of the tolerant species were increased.

In an evolutionary sense a polluted watercourse may be regarded as a new habitat and as such can be expected to support but a few species or as Odum (1971) has stated "diversity tends to be high in older communities and low in newly established ones". Applying this concept to pollution studies a clean stream with its greater variety of species has a high diversity and a polluted one, with its fewer species, a low diversity. Diversity is, to a large extent, based, according to Margalef (1956), on what he called information theory. Information was equated with the uncertainty that a species, selected at random from a sample, would be different to or the same as the previous one selected. Thus in a sample containing a large number of one particular species the uncertainty, that is the information, would be small. The greater the information gained, the greater would the diversity be. Wilhm (1972) explained, that diversity has at least two meanings; species diversity refers to the number of species in a specific area, the more species being present the greater the diversity; whereas dominance diversity is based on the relative numbers of individuals in each species, the more equal the distribution the greater is the diversity. Wilhm and Dorris (1968) deomonstrated that by pooling the animals from successive sample units from a station, there was little change in the diversity value (dominance diversity) subsequent to the fourth of ten pooled samples and that, therefore, the diversity index is relatively independent of sample size. In this way dominance is taken into account and the contribution to the total diversity by a rare species, which might be found after the fourth sample unit, is minimal.

The diversity index $\bar{d}$, is calculated by using the formula $\bar{d} = - \sum^{t} \left[\left(\frac{ni}{N}\right) \log_2 \left(\frac{ni}{N}\right) \right]$ where t = number of species

Shannon-Wiener

n = number of individuals in the i th species, and

N = total number of individuals.

Wilhm and Dorris (1968) reported, that in a survey of a stream in Oklahoma, receiving municipal and industrial wastes, good agreement was found between the diversity index and other parameters measured. Having evaluated information derived from a number of surveys Wilhm (1972) proposed, that diversity index values in excess of 3 indicated clean conditions, values between 1 and 3, areas of moderate pollution, and values of less than 1, heavy pollution. The range of values obtained by Cole (1973) were in general agreement with this proposal, but it was found that "the degree of stream degradation is not represented adequately by the indexes alone in the areas that had been invaded by macrophytes or in pool edges". He also emphasised that only the increase in habitat diversity, brought about by increased macrophytic growth, increased the diversity in a grossly polluted stretch. Edwards <u>et al</u>. (1972) found the highest diversity index values in the unpolluted head-waters of the Taff and Cynon and the lowest indices in the polluted stretches.

Mackay <u>et al</u>. (1973) found that the diversity index for 50 unpolluted streams varied between 1.3 and 2.5, whereas in polluted streams values between 0 and 2.4

were obtained. They pointed out, however, that even in the absence of pollution the different physical and chemical characteristics encountered would be expected to have an effect on the diversity index. They proposed the establishment of a baseline of physical and chemical attributes of a stream in order to be able to predict departures from normality. In a survey of the Lower Sabine River, Hendricks et al. (1974) were unable to separate the influences of natural factors such as high flows and salt-wedge intrusions from those caused by pollution from a paper mill. Also, samples taken near the banks and in shallow stretches yielded more species than those from mid-stream where coarse sand was found. Wilhm (1972), considering the differences in weights between individuals of different species, thought that the substitution of biomass units instead of numbers in the diversity index formula would correct this discrepancy. Considerable differences were revealed when comparing data derived from numbers and from biomass of the same samples over a period of six months. Cole (1973) found similar differences from samples collected in each season.

Nuttall and Purves (1974) in a comparative evaluation of the diversity index, the Lothians index, the Trent index, the Chandler score system and the Carpenter index proposed by the Department of the Environment, found that the Lothians and Carpenter indices classified all the sampled stations as unpolluted. The Chandler score revealed pollution at one station, the Trent index at two stations and the diversity index at five stations. Also the diversity index distinguished between the effects of pollution and the effects of moorland run-off.

Not necessarily | but it helps.

The main drawbacks of the diversity index seem to be the need for computer time (Nuttall and Purves, 1974), and its inability, according to Hendricks <u>et al</u>. (1974), but not according to Nuttall and Purves (1974), to distinguish between the effects of pollution and those caused by natural phenomena. Chutter (1972) also warned that to rely on the diversity index is sometimes wasteful of readily available information derived from the types and abundance of animals obviously present.

None of the systems yet devised and in use seems to take into account seasonal variation and, in some cases, absence of species. Nor is there any adjustment made for the effects of physical factors of the habitat. Finally, no index, as yet, distinguishes between the effects of organic and inorganic pollution.

Hynes (1960) suspected that the formal, rigid methods described above led to "rigidity of thought and approach", that reliance on "arithmetical manipulation" can lead to erroneous conclusions, and that the presentation of the raw data in table form was essential in the present state of our knowledge. However, as Hawkes (1962) emphasized there is a need for biological data to be codified to some extent in order that it is comprehensible to non-biologists in administrative positions.

1.4. Methods of Sampling Stream Riffles

Various methods for the quantitative and qualitative sampling of benthic invertebrates of stream riffles have been devised. Most of them incorporate nets of various types, either hand-held or as part of some more elaborate apparatus. A number of reviews of sampling methods have been published, notably by Macan (1958), Welch (1948) and since 1967 (when this study was started) by Hynes (1970) and in Edmondson and Winberg (1971). Most of the methods are carried out either for a fixed time or over a fixed area of substratum.

Possibly the simplest methods are those which involve the use of a hand-net, which is held vertically on the stream bed with the opening facing upstream. The area in front of the net is disturbed either by turning stones by hand or by kicking the substratum with the foot, the so-called 'kick method' of Hynes (1961). The mesh-size of the net used is important. Coarse-meshed nets tend to lose the smaller organisms and immature stages, but fine-meshed nets become clogged quite rapidly and so impede flow into the net. Percival and Whitehead (1929) found that Entomostraca, some Acarina and very young stages of chironomid larvae were lost using coarse nets (0.5 mm. mesh). Macan (1958) in a comparison between catches made using coarse-(20 threads/in.) and fine-meshed (180 threads/in.) nets, found that for Rhithrogena less than 3 mm. long and for Baetis less than 5 mm., considerably more specimens were caught using fine-meshed nets, but that for longer specimens the numbers caught by each type of net were about equal. Zelt and Clifford (1972) using nets of mesh size 720 μm and 320 μm found similar results to those of Macan and emphasized the importance of body-shape, Nemoura nymphs being retained by the coaser net but the more streamlined Baetis being lost. There is an eddying effect at the mouth of both net types, but it is more pronounced with the fine-meshed net.

When hand-turning of stones is done, Macan (1958) found that in 5 minutes of collecting only $0.10m^2$ was covered. Moreover, hand-turning is an unpleasant task in cold weather, especially if a large number of stations is to be sampled. Also the depth which can be sampled is limited by the length of the collector's arm.

Streams of greater depth can be sampled using the kick method. Hynes (1961) used a triangular-shaped hand-net 28 cm. wide which had six threads per cm. Morgan and Egglishaw (1965), using this method, kicked four times in an upstream direction for a distance of about 18 in., each kick digging deeper into the substratum. They maintained that the method could be used on a variety of substrates from sand to bedrock and they emphasized the speed of performance. Elliott and Minshall (1968), using a net with 25 threads/cm., did 2 minute samples either by hand-turning of stones or by kicking and found that the kick method collected more animals, probably, they suggested, because a greater area was covered. The kick method was rejected, however, by Chutter (1968) for sampling streams with large populations of Simulium. Coleman and Hynes (1970) found that kick sampling disturbed the substratum down to about 5-7 cm. In an evaluation of the kick method, Frost et al. (1971) found that less than 20% of the animals present were collected, that 40% of the fauna was lost through the pores of the net and that more than 30% of the disturbed material by-passed the sample net. They used a net with 24 strands/cm. and collected on transects across streams or for a fixed time (1 or 5 mins.).

Samplers which could be described as further developments of the hand-held net are those of Surber (1937) and Macan (1958). Surber's apparatus, which is widely used, consists of a hand-net to the front of which is fixed a frame for marking out the area (1 ft^2) to be sampled. The stones enclosed within this area are picked up and cleaned in the mouth of the net (23 meshes/in.). Needham and Usinger (1956), using the sampler on a fairly uniform riffle, found that 73 samples would be needed at each station to give statistically accurate results of total numbers and so they rejected it for quantitative sampling. They also stated that it could be used only in depths up to arm's length, though Dean and Burlington (1963) used it in waters up to 3 ft. deep. Chutter and Noble (1966) tested the reliability of this method using a net with 23 mesh/in. They took ten samples at each station at sites of similar stone size and concluded that five samples yielded between 77% and 94% of the species found in ten samples. Using a modified Surber sampler (net with 24 meshes/cm.) Learner et al. (1971) took four samples across the river at each station. Cole (1973) took sets of 12 samples (each 230 cm^2) at each station. Hynes (in Edmondson and Winberg, 1971) did not recommend the Surber sampler for quantitative studies on production and stated that "its efficiency varies for example with water level, mesh size, current and the amount of organic matter in the stream bed."

Macan's sampler has a square frame, the bottom of which has a cutting edge, and is welded to a handle fixed at an angle. A coarse and a fine net are fastened to the frame and the sampler is pushed into the stream bed and then upstream for a fixed distance, sampling an area of 0.05 m^2. In comparing this shovel sampler with the hand-net method of sampling, Macan (1958) found that the shovel was more efficient in collecting very small specimens of Rhithrogena, but less efficient in collecting larger specimens. Many more Baetis rhodani were collected with the net, mainly because the baetids swam away when the shovel disturbed the substratum. Also the shovel tended to ride over large stones or to push them aside, thus losing a considerable proportion of the fauna. Only 2 or 4 samples were taken at each station, which was probably insufficient to overcome what is a non-random distribution of most species. Elliott (1967) took 4 samples in a diagonal transect across the stream in an effort to compensate for this non-random distribution.

A variety of boxes and cylinders have been constructed for sampling a fixed area, but they can be used only in relatively shallow waters. Both boxes and cylinders are pushed into the substratum and the enclosed area is sampled either by lifting or digging the stones out or by stirring the bottom and collecting the dislodged animals with a hand net. A cylinder sampler, which relies on a current for its operation, is that of Neill (1938). This has a mesh-covered opening on the upstream side and on the opposite side a similar opening over which a net is fixed. Large stones are lifted by hand and the enclosed substratum is stirred, the contents being carried into the net by the current.

Macan (1958) concluded that it was impossible to fit a box closely to the substratum and that whilst being lowered the box deflected the current downwards, scouring the prospective sampling area. Neill's cylinder is open to similar objections. To overcome the problem of seating the sampler, some workers have constructed cylinders with a serrated lower edge (Hawkes and Davies, 1971; Hynes in Edmondson and Winberg, 1971). This is the method recommended by Hynes for production studies.

Some workers (Moon, 1935; Egglishaw, 1964) have used trays of substratum set into the bed, which were then lifted out after a specific time. These methods, however, are thought to be somewhat selective in the species which are thus sampled.

The use of artificial substrata, consisting of porcelain or hardboard multiplates or of baskets filled with stones, have been investigated by some researchers. Mason et al. (1973) found that colonization by invertebrates of such substrates depended upon length of exposure, type of material and surface area.

A number of workers have emphasized the non-random nature of the distribution of macroinvertebrates in stream riffles and Elliott (1971) has discussed it in some detail. He summarised the major factors to be considered in quantitative sampling as "1. the dimensions of the sampling unit (quadrat size), 2. the number of sampling units in each sample, and 3. the location of sampling units in the sampling area". Of the methods described above, the quadrat size varied from about 0.05 m^2 (Macan, 1958; Hawkes and Davies, 1971) to 0.09m^2 (1 ft^2) for the Surber sampler or 0.13m^2 (1.5 ft^2) for the kick method used by Morgan and Egglishaw (1965). As Macan (1958) emphasised, the larger the sampler the smaller the sampling error.

As regards sampling units, Hynes (1961) used 10 kick sampling units, Chutter and Noble (1966) 10 Surber sampling units, Dean and Burlington (1963) 3 Surber units, Cole (1973) 12 Surber units and Needham and Usinger (1956) a theoretical 73 Surber units. Macan (1958) and Elliott (1967) used 2 or 4 shovel sampling units and Hawkes and Davies (1970) 3 cylinder sampling units.

It is evident, that with the smaller number of units, especially when used with the smaller quadrat size, the method is less effective in detecting non-random distribution. A better chance of sampling all the micro-habitats is found when a large number of sampling units is used, though this number should be limited before unwieldy amounts of material are collected.

1.5. Toxicity of pollutants to macroinvertebrates

Comparatively little toxicity testing has been done to determine the tolerance of macroinvertebrates to various toxic pollutants. Warren (1971) has examined the theory of toxic effects on organisms and has shown, that the action of various toxicants is influenced to a considerable extent by the other constituents present in the solution. Not only is there interaction between different metals, but also between metallic ions and non-metallic ions. A number of kinds of interaction have been described by Warren (1971) and may be summarised as follows. A strictly additive interaction is shown when two equally toxic solutions are mixed in various proportions and each mixture is equally toxic to either of the solutions tested alone. If two solutions of equal amount are mixed and the toxicity is found to be equal to half of either solution when tested separately, then there has been no interaction. When the additive reaction is slightly less than strictly additive, this is called an infra-additive interaction, and if slightly more, a supra-additive interaction. A toxic effect, produced by mixing two solutions, which is less than expected is termed antagonism. Antagonism can be brought about by the interaction of two metals in which the toxicity of both is reduced, or of just one or by the toxicity-reducing effect of non-metallic ions such as Mg, Ca, Na or K (Jones, 1938; Hawkes, 1962). Jones (1938) displayed the antagonism between lead nitrate and copper nitrate, using Polycelis nigra, Tubifex tubifex and Gammarus pulex as test animals. The results showed that lead nitrate reduced the toxicity of copper nitrate, but copper nitrate did not seem to reduce the toxicity of lead nitrate solutions. At concentrations of lead above 0.005N, however, the mixed solutions were more toxic than copper nitrate alone. An antagonistic action of calcium on the toxicity of copper sulphate was found by Learner and Edwards (1963) in tests on species of Nais.

The toxic action of lead solutions alone has been studied. Jones (1938) reported that solutions of lead nitrate were toxic to Polycelis nigra at concentrations above 0.03N, down to 0.01N for Gammarus pulex and above 0.02 for Tubifex tubifex. In a series of tests using solutions of a number of toxic metals Warnick and Bell (1969) discovered that a stonefly, Acroneuria lycorias, showed a 50% survival of more than 14 days in a 64 mg/l lead solution. Ephemerella subvaria, in a lead solution of 16 mg/l had a 50% survival in 7 days and Hydropsyche betteni 50% survival in 7 days in a solution of 32.0 mg/l. The considerable effect of pH on the toxicity of lead to tubificid worms was shown by Whitley (1968). Tests in modified Knopp's solution at 20°C showed, that the 24 hr. LC50 at pH 6.5 was 49.0 mg/l and at pH 8.5, 27.5 mg/l lead. At pH 7.5, 100% of the test animals survived the 24 hr. test period. He suggested, that precipitation of a mucousmetal complex on the body wall, restricting respiration, was the action induced by the toxic metal.

Copper-nitrate solutions were reported by Jones (1938) to be toxic to Gammarus at very low levels. The survival time in solutions of 13 parts of copper per hundred million water was under 4 hours. Polycelis nigra was affected in solutions of above 0.015N. The 96 hr. LC50 for Acroneuria lycorias was reported by Warnick and Bell (1969) to be 8.3 mg/l and for Ephemerella subvaria the 48 hr. LC50 was 0.32 mg/l Cn. Hydropsyche betteni showed a 50% survival in 7 days of a 32.0 mg/l. copper solution. Learner and Edwards (1963) studied the effect of copper compounds on species of Nais. The median survival time in copper sulphate was about one-third (70 mins.) as long as in copper sodium citrate (over 200 mins.) in hard water. In soft water, however, at pH7 the median survival time in 1 mg/l copper sulphate solutions was about 35 minutes. It was suggested that calcium was having an antagonistic effect on the copper in hard water. It was also found, that at pH4 copper was less toxic than at pH7 and that Nais communis was more resistant to copper sulphate at pH7 and pH4 in soft water than Nais variabilis was. Bucksteeg (1965) summarised the tests of several workers on the effects of copper. The toxic limits of copper were reported as 4-3 mg /l for Chironomus sp., 4-8 mg/l for Simulium sp., 0.4-0.8 mg/l for Gammarus sp. and 0.03-0.04 mg/l for Daphnia magna. According to Martin (1972) the 48 hr. LC50 for Gammarus pulex was 0.72 in water with a hardness of 100 mg/l $CaCo_3$ and 4.4 at 300 mg/l.

Because calcium has an antagonistic effect on zinc, the toxicity of zinc varies with the hardness of the water. Its toxicity is also influenced by the pH of the water. Whitley (1968) found that the 24 hr. LC50 for tubificids was 46 mg/l at pH 7.5, slightly below 10 mg/l at pH8.5 and considerably less than 10 mg/l at pH 6.5. The killed worms showed the same secretion of mucous as when they were tested in lead solutions. Martin (1972) reported that the 48 hr. LC50 for Gammarus pulex was 2.4 mg/l zinc at 100 mg/l Ca Co_3 and 5.7 mg/l at 300. According to Warnick and Bell (1969) Acroneuria lycorias showed a 50% survival after 14 days in a 32.0 mg/l solution of zinc sulphate; 50% of Ephemerella subvaria survived 10 days in a 16.0 mg/l solution and 50% of Hydropsyche betteni lived 11 days in a 32.0 mg/l solution.

It was shown above that pH has an effect on the degree of toxicity of metals in solution. Whitley (1968) has shown, that between pH6 and pH9, tubificids in Knopp's solution at 20°C survived well for 24 hours, but above and below these values there was considerable mortality. None survived at all at pH 4.2 and pH11. Bell (1971) studied the tolerance of insects to low pH and its effect on emergence. He reported that at a temperature of 18.5°C and a hardness of 44.0 mg/l Ca CO_3 the 30 day TL 50 for Brachycentrus americanus was 2.45 pH. Others including caddisflies, stoneflies, mayflies and dragonflies, showed various tolerances up to pH 5.3 for Ephemerella subvaria. The pH at which there was 50% successful emergence was higher; for example, for B.americanus it was at pH 4.0 and for E.subvaria it was at pH 5.9.

Phenols and cresols tend to inhibit bacterial activity so their breakdown is rather slow (Klein, 1962). The effects on fish by phenols are well-described (Herbert, 1962; Brown, 1968; Herbert and Vandyke, 1964; Brown et al, 1970), but there is little reported about the effects on invertebrates. Whitley (1968) emphasized the importance of pH on the toxicity of phenol. In a solution of 0.25 p.p.m. sodium pentachlorophenate (PCP) no tubificids survived 24 hours at pH 6.5, but at pH 8.5 and in more alkaline solutions there was a 100% survival. The 24 hr. LC 50 was 0.31 mg/l at pH 7.5, 0.67 mg/l at pH 8.5 and 1.4 mg/l at pH 9.5. In a later paper (Whitley and Sikora, 1970), it was shown that at both pH 8.5 and pH 9.5 there was an increase in respiration rate after exposure to PCP. Emery (1970) considered that the upper limits of cresols for Gammarus sp. and Asellus sp. was between 0.52 and 0.70 mg/l^{-1}.

Whitley and Sikora (1970) studied the activity of nickel on the respiration rate of tubificid worms and found that the rate was affected very little by nickel, and that nickel did not activate the precipitation of mucous. According to Warnick and Bell (1969), the 96 hr. LC 50 for Acroneuria lycorias was 33.5 mg/l Ni and for Ephemerella subvaria 4.0 mg/l. Hydropsyche betteni survived more than 14 days at a nickel concentration of 64.0 mg/l. Other metals tested by Warnick and Bell (1969), using these three insect species, included cadmium, iron, cobalt, chromium and mercury. Ephemerella was the most susceptible and _Acroneuria_ the most resistant to all of these metals except mercury, where the 96 hr. LC 50 for all insects was 2.0 mg/l Hg. _Ephemerella_ was particularly susceptible to iron sulphate, the 96 hr. LC 50 being 0.32 mg/l.

Of increasing importance during the last thirty or forty years have been insecticides and to a somewhat lesser extent synthetic detergents. Tests have been made by a few workers to determine the tolerance of various aquatic organisms to insecticides. Gaufin _et al_. (1965) tested ten organic insecticides and discovered that _Daphnia magna_, _Gammarus lacustris_, _Hydropsyche_ sp., and _Acroneuria_ sp. were extremely sensitive to these insecticides, but _Ephemerella grandis_ and _Arctopsyche grandis_ were less sensitive. Anderson (1959) reported that _Daphnia magna_ was very sensitive to malathion, parathion and DDT, but quite resistant to dieldrin and endrin. Muirhead-Thomson (1973) tested DDT toxicity and reported that dragonfly nymphs survived 20 mg/l DDT for 1 hour, but concentrations as low as 0.05 for 1 hour produced 100% mortality in _Baetis_ nymphs and _Simulium_ larvae.

Solutions containing two domestic detergents were found by Roberts (1954) to be toxic to _Gammarus pulex_ within 7 days at concentrations above 2.5 mg/l. Tests on _Cladophora glomerata_ and _Eurhynchium rusciforme_, by Hynes and Roberts (1962), showed that these plants were relatively resistant to detergents, but that _Ranunculus pseudofluitans_ and _Potamogeton pectinatus_ were seriously affected.

1.6.1. Methods of toxicity testing

Most of the toxicity studies, on the effects of heavy metals and poisons, on aquatic fauna have been done in large aquaria, supplied with a renewed water supply, using fish as the test animals (Erichsen Jones, 1964; Herbert and Merkens, 1952; Lloyd, 1960; Lloyd, 1961; Skidmore, 1964; Herbert and Shurben, 1964; Herbert and Vandyke, 1964; Ball, 1967a and 1967b; Brown et al, 1968; Brown, 1968; Skidmore and Tovell, 1972; Sprague, 1969). Recently, Stott and Cross (1973) have used laboratory channels for testing the reactions of roach to D.O. and CO_2 concentrations.

It is not proposed to review the very extensive literature on fish toxicity studies, since it is outside the scope and intentions of this study. Comparatively few toxicity studies seem to have been done using invertebrates, especially in laboratory streams. Jones (1938), in his study of the antagonisms displayed between lead nitrate and copper nitrate and the differential effects on Polycelis nigra, Gammarus pulex and Tubifex tubifex, prepared his range of solutions using very soft tap water, immersed the animals in these solutions and noted the times of death. In testing the toxic effects of sodium chloride, chlorine and copper to Nais spp., Learner and Edwards (1963) used 200 ml. of each solution with ten worms in each and tested under static conditions. Whitley and Sikora (1970) studied the effects of pollutants on the respiration of tubificids. The worms were kept in modified Knopp's solution, and the tests were carried out in white enamel pans containing

Knopp's solution, the test material at various concentrations and a buffer.

A small-scale, pneumatically-operated, toxicity-testing apparatus has been developed by the Water Pollution Research Laboratory (Water Pollution Research, 1972) for testing fish. It includes a volumetric dilution unit which can deliver, in sequence, different concentrations of poison to the test flasks and could easily be used for testing toxic effects on invertebrates. Martin (1972) studied the toxic effects of metal salts on Gammarus pulex, using glass dishes containing 800 ml. of solution, at a hardness of 100 mg/l ($CaCO_3$) at 10°C in static conditions. He also used a small perspex trough for some tests.

Shaefer and Pipes (1973) used the rotifer Philodina roseola in their experiments, to test the toxicity of chromate and arsenate. The rotifers were kept in solutions of various concentrations in an incubator and at various temperatures, and mortality was recorded daily. The toxicity of cadmium, mercury, cobalt, zinc and lead on the protozoan Tetrahymena pyriformis was tested by Carter and Cameron (1973). A suspension of Tetrahymena mixed in the test solution was pipetted into Petri dishes and the drops covered by mineral oil to prevent evaporation.

Warren (1971) and his co-workers at Oregon State University have used laboratory streams to study the tolerance to kraft mill effluents shown by crayfish, stonefly nymphs, caddisfly larvae and snails, but the methods and results were not published in easily accessible form.

1.6.2. Methods of determining metal concentrations in macroinvertebrates

A few workers (Mathis and Cummings, 1973; Butterworth et al. 1972) have investigated the concentration of metals in selected aquatic invertebrates, and some (Warnick and Bell, 1969) the concentrations found in animals after toxicity testing. Other investigators (Martin D.F., 1968; Tomlinson and Renfro, 1972) have warned of the inaccuracies which can arise through adsorption of metals onto collecting vessels and laboratory ware. Tomlinson and Renfro (1972) in investigating losses of Zn^{65} to inorganic surfaces, found that "glassware with surface area/sample volume ratios as small as those of 20 ml. volumetric pipettes adsorbed 7-11% of the contained sample activity". They found that the use of polypropylene apparatus reduced zinc losses significantly. Adsorption onto larger apparatus with low surface area/volume ratios was found to be negligible.

Bowen (1966) recommended that the containing vessel should be made of polyethylene, silica or hard glass, but went on to state that hard glass is a potential source of most elements, and that samples of polyethylene have been found to contain, for example, up to 2 p.p.m. Cu and 4 p.p.m. Zn. In order to overcome these problems, various methods for cleaning vessels have been proposed. Bowen (1966) stated that polyethylene was best cleaned with ethanol, and glassware by boiling in HCl. Tomlinson and Renfro (1972) found that rinsing glassware with HCl, deionised water and acetone inadequate and stated that pre-rinses with the sample liquid or treatment of glassware with chemicals which produce hydrophobic effects reduce errors considerably.

Bowen (1966) discussed the "extensive possibilities for systematic errors in the analyses themselves". In wet chemical methods there is contamination from the oxidizing acids, which are used to digest the animal material and also some losses of volatile elements. Contamination from the crucible and the furnace walls are the errors induced by dry ashing. Also there may be losses by volatilization or by adsorption onto the crucible. In spectroscopic methods, where the sample is completely volatilized, there are serious losses. Only by radioactive techniques are errors, due to contamination, not found, but other errors are still encountered. Examination of manufacturers' chemical catalogues indicate that nitric acid specially made for use in atomic absorption spectrophotometry has greater trace ámounts of zinc than do commercial or analytical grades.

Mathis and Cummings (1973) analysed the metal content of tubificids, clams, fish and bottom sediments. Samples of tissue were heated at low heat in a mixed acid solution (5 vols. of nitric acid conc. to 1 vol. of perchloric acid conc.) until all the tissue had dissolved. The solution was made up to 25 ml. with distilled deionised water before aspiration into an atomic absorption spectrophotometer. Concentrations of metal impurities in the acids were deducted from the readings.

There seems to have been no agreed method of expressing results of such analyses; some workers have quoted results as a fraction of the dry weight, whilst others have referred to fresh weight or to ash-free dry weight. Bowen (1966) regarded the ash content of organisms as variable and preferred the use of dry weight as a reference.

I would like to know why much of this work was carried out,

1.7. Objectives of studies

The objectives of the studies were as follows:-

1. to determine the extent and degree of pollution in the part of the Stour catchment area studied.
2. to determine the distribution of the benthic macrofauna and to correlate this distribution with pollution.
3. to determine, if possible, which species were tolerant and which were intolerant to organic and inorganic pollution.
4. to determine the effects on the benthic fauna of specific discharges such as those from sewage treatment works.
5. to record the sequence of reappearance of species in zones recovering from pollution.
6. to compare the efficiency of three biotic indices in interpreting results from stream surveys.
7. to observe the sequence of colonization of percolating filters by microfauna and by grazers.
8. to determine the composition of the microfauna and macrofauna and their vertical distribution.
9. to record the seasonal sequence of dominance within the microfauna and the macrofauna.
10. to determine the effect of the fauna on the film and the effect of film accumulation on the fauna.
11. to determine, where possible, the effects of periodicity of dosing and strength of feed on the film and fauna.
12. to determine the effects of recirculation and

A.D.F. on film and fauna.

13. to correlate film and fauna with the chemical results and works efficiency.

14. to determine by toxicity testing the tolerance of *Asellus aquaticus*, *Gammarus pulex*, *Baetis rhodani* and *Limnaea pereger* to zinc.

15. to determine the effects of temperature, hardness and dissolved oxygen on the toxicity of zinc.

16. to correlate the results of the toxicity tests with the distribution of benthic macrofauna in the Stour catchment area.

2. Description of the area, streams and treatment works

2.1. Geology, population and industry

2.1.1. Geology

Except for the westernmost edge, the whole area studied lies within the South Staffordshire coalfield (Edmunds and Oakley, 1947), an oval-shaped field, which stretches from Rugeley in the north to the Lickey Hills in the south. Coal mines were worked until very recently and old mine shafts can be found almost throughout the area.

Most of the rocks of the area are sedimentary, with the notable exception of the igneous sill of Rowley Regis in the north-eastern part. The strata comprise various sandstones (Permian sandstone of the Clent Hills, Keuper, Bunter and Upper Ludlow strata), shales, marls and also some Brick Clay at Old Hill. The northern edge of the area is bounded by the prominent limestone (Wenlock limestone) features of Wren's Nest and Dudley Castle Hill, which form part of the watershed between the streams flowing westwards towards the River Severn and those flowing eastwards towards the River Trent. The River Stour is a tributary of the River Severn.

The slope of the area is, therefore, from the Dudley Castle Hill (700 ft.) in the north-east, south-westwards to the Severn Valley. The River Stour and its tributaries have cut through the soft strata to produce a series of hills and valleys which become wider in the western part of the area.

2.1.2. Population

The estimated population in 1971 of the area comprising part of Dudley, Halesowen, Stourbridge, Brierley Hill and part of Warley was about 300,000.

2.1.3. Industry

The area studied lies at the southern end of the South Staffordshire Coalfield and forms part of what is known as 'the Black Country'. The principal industries at present are metal manufacturing, engineering, brick-making, glass-making, forging, casting, galvanising and plating.

Industry became established in the Black Country because of the easy access to coal, iron ore, sand and clay. From about the middle of the 18th century until the beginning of the 20th century, the main industries were the so-called extractive industries (Wadsworth and Jones, 1973), concerned with iron manufacturing. Based on this iron manufacture, the making of nails and chains was established, especially in the Cradley, Old Hill, Netherton and Quarry Bank districts. Iron was first worked in the area in the early 14th century and by the 17th century large numbers of furnaces were in operation. The first clast furnace was established in the late 18th century at Brierley Hill, and by the late 19th century iron manufacturing was superceded by steel making. Since 1900, the emphasis has been more on metal fabrication and light engineering.

Coal had been used in glass-works, salt-works and brick-making since the 18th century, after which the demand increased greatly and by the mid 19th century most of the coal was exhausted in the Dudley area. Today, coal-mining is almost non-existant, except for some open-cast mining.

The manufacture of glassware dates from the 16th century, in the Wordsley, Brierley Hill and Stourbridge area. The local clay was used as fire clay. Nowadays, crystal glass and cut-glass are the principal products.

2.2.1. Description of the River Stour and its tributaries

The River Stour (Fig. 2.1. page 73) rises on the north side of the Clent Hills and flows in a north-easterly direction, through farmland and woodland, towards Halesowen. South of Halesowen, the river turns northwards and flows through the town in a steep-sided valley, which becomes wider to the north. The river is joined on its right bank, first by Illey Brook and then, at Furnace Hill, by the Coomeswood tributary. Factories line most of the bank between these two tributaries. Illey Brook runs through farmland upstream of Halesowen, but its banks are bordered by residential districts, together with some industry on its course through the town. The Coombeswood tributary is culverted where it flows beneath the municipal refuse tip and the rest of its course is through a new industrial estate.

From Furnace Hill, the river takes a north-westerly and then a westerly course through a steep-sided, wooded valley as far as Hayseech, where the valley becomes wider and has woodland on the south bank and parkland on the north bank. This continues as far as Bellevale, where the river is joined by Lutley Gutter.

This tributary drains a mostly residential area and some decreasing farmland. Proceeding westwards, the river flows through a gorge-like valley to Overend; there is some industrial development on the south bank. At Overend, the river continues underground, via a tunnel, for about two hundred yards. West of Overend, the valley becomes wider and more industrialised.

At Maypole Hill (Cradley Forge), the river receives the combined waters of Black Brook, Saltwells Brook, Old Hill Brook and Mousesweet Brook. Saltwells Brook and Black Brook, which takes overflow water from Dudley Canal, flow through woodland and mixed residential and industrial areas, whereas Mousesweet Brook, which is partially culverted and Old Hill Brook, which is completely culverted, run partly through residential areas and partly through heavily industrialised areas, where they receive discharges containing toxic metals.

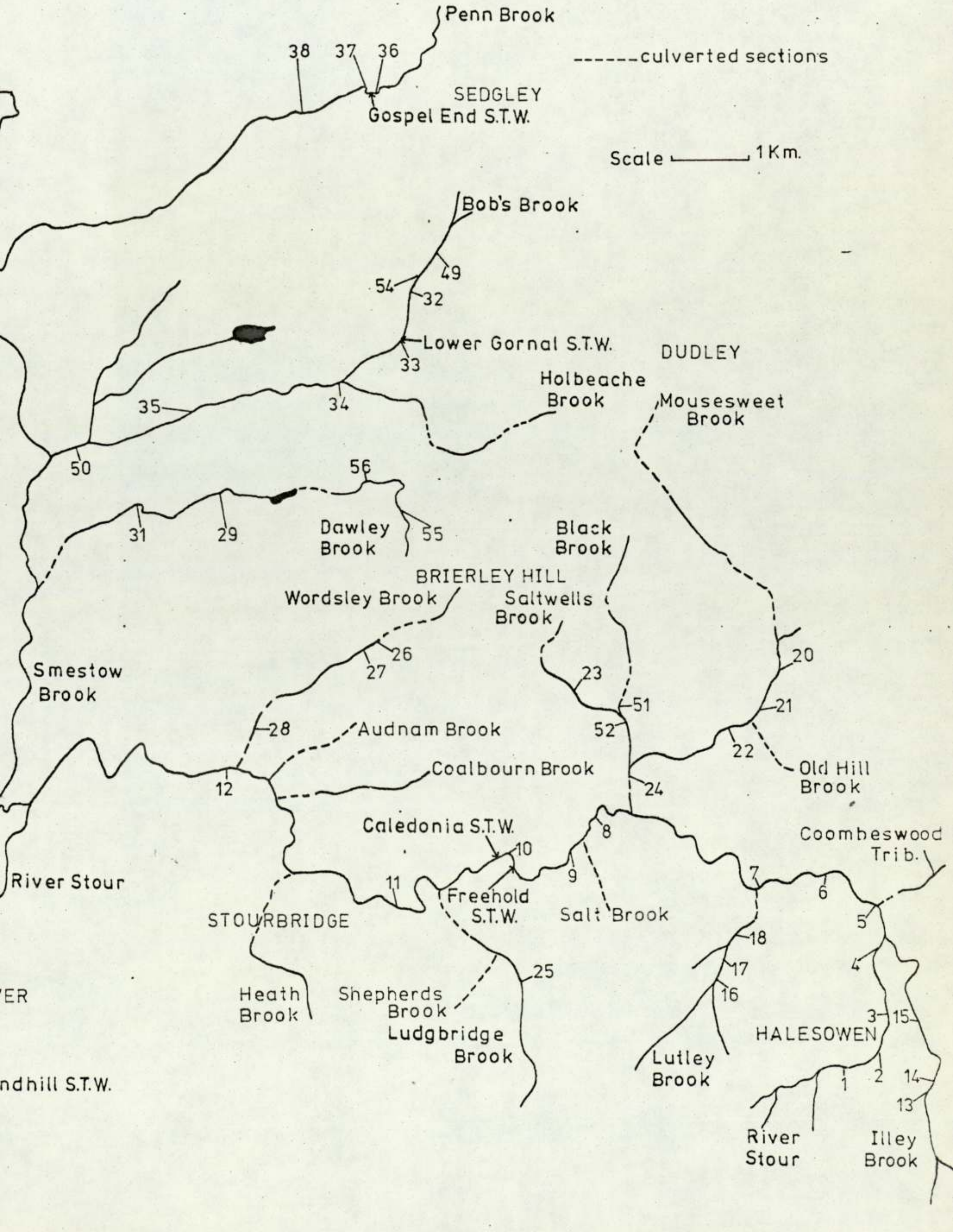
About half a mile downstream of Maypole Hill, the now culverted Salt Brook joins the river and a further half mile downstream, an unnamed, partly culverted, brook enters the river, north of Bromley Street, Lye. At Lye, the effluents from Freehold S.T.W. and Caledonia S.T.W. discharge to the river as it meanders through a wider valley. Shepherds Brook and Ludgbridge Brook, which joins it, flow through residential areas before joining the Stour at Stambermill. Downstream of the railway viaduct at Clatterbatch, an unnamed, partly culverted, stream from Upper Swinford, Stourbridge, enters the river.

Passing through the heavily industrialised district of Stourbridge, the river receives the partly culverted Heath Brook at Lowndes Road, and then turns northwards towards Amblecote. This area is a conglomeration of housing, light industry and heavy industry. The valley here was subject to flooding at one time, but remedial work by the former Severn River Authority has alleviated this problem. Three small tributaries, Coalbourn Brook, Audnam Brook and Wordsley Brook enter the river here, within a quarter of a mile of each other. The upper part of Coalbourn Brook has been obliterated during recent years by open-cast coal-mining. Audnam Brook has been extensively culverted and Wordsley Brook valley is the site of large steel works and other industries as well as housing.

After the confluence with Wordsley Brook, the river flows westwards again through farmland to Prestwood. Here, south of the grounds of Prestwood Sanitorium, it is joined by Smestow Brook, and then turns southwards flowing through farmland to Kinver. The river meanders through Kinver village, where steep outcrops of sandstone line the left bank. South of Kinver, at Whittington, the discharges from Whittington Farm and, until 1972, Roundhill Farm, enter the river. The Roundhill Sewage Farm was superceded in that year (see 2.3) by Roundhill S.T.W., which discharges to the river at the same point as the former Farm effluent. About half a mile further downstream the river receives the effluent from Kinver S.T.W., and then continues southwards through farmland towards Wolverley and Kidderminster.

The other streams included in this study, namely

Fig.2.1. BIOLOGICAL SAMPLING STATIONS



Bob's Brook, Holbeache Brook, Dawley Brook and Penn Brook, all flow in a generally south-westerly direction to Smestow Brook. They drain largely residential areas and farmland, though in recent years in the case of the valley of Dawley Brook, new industrial estates have been established.

2.2.2. Description of the biological sampling stations

The streams of the area and the position of each biological sampling station and of the discharge points of the sewage treatment works is shown in Fig. 2.1. (page 73). In an industrialised catchment area such as that of the River Stour, the effects of interference by man are perhaps most noticeable. Streams have been culverted, resulting in a great reduction in the self-recovery potential, whilst others run in open culvert which is almost as detrimental. The most noticeable effect as regards sampling was the deposition of rubbish. The watercourses in this catchment area have been used as a depository for all manner of unwanted household and industrial rubbish, so much so that sampling proved extremely difficult at times at some stations.

A brief description of each sampling station is given below. Certain features of the substratum have changed slightly from time to time, but generally the station has remained as described. Factors such as width, depth, current velocity and weed cover are included in the Appendix Tables 1-131.

From its source in the Clent Hills, the River Stour runs through steep woods to meadowland, where it flows in deeply-cut meanders to station 1.

River Stour

Station 1. (South of Manor Way, Halesowen, S.0.98 964825) - loose, rough stones resting on stones embedded in sand, size range 0.5-4 cms., overhanging Willow and Alder on left bank.

Station 2. (u/s Manor Way, Halesowen, S.0.98 968827) - rough stones embedded in sand and silt, size range 1-9 cms., predominantly sandy at times of low flow.

Station 3. (d/s Great Cornbow, Halesowen, S.0.98 968835) - rough stones and boulders, size range 10-25 cms., occasional rubbish.

Station 4. (West of Dudley Road, Halesowen, S.0.98 968840) - mixed stones, av. size 2 cm., much rubbish at times; stretch immediately upstream dredged in October, 1971.

Station 5. (Furnace Hill, Halesowen, S.0.98 968844) - just upstream of waterfall and downstream of Coombeswood tributary. Smooth, loose stones resting on stones embedded in sand, size range 1-5 cms., rubbish found; sewage fungus present especially January to May, 1972 and January to July, 1973.

Station 6. (u/s Hayseech, Halesowen, S.0.98 959849) - smooth, loose stones; size range 1-8 cms; substratum changed from time to time by fluctuating extent of bank of stones and sand; occasional sewage fungus - Hanuary to May 1972, January to March 1973, overhanging Willows.

<u>Station 7</u>. (u/s Corngreaves Road, Bellevale, S.O.98 952847)

- stones embedded in sand and silt; usually some rubbish, overhanging trees.

<u>Station 8</u>. (d/s Bower Lane, Quarry Bank, S.O.98 931853)

- stony and silty with fluctuating amounts of rubbish.

<u>Station 9</u>. (North of Bromley Street, Lye, S.O.98 928848)

- downstream of partially culverted stream; loose stones with sand which varied with the extent of weed growth; also iron deposits and bricks.

<u>Station 10</u>. (bridge between Freehold S.T.W. and Caledonia S.T.W., S.O.98 919850)

- stony with bricks.

<u>Station 11</u>. (Clatterbatch, S.O.98 908843)

- downstream of culverted stream from Upper Swinford; stony and silty with bricks and rubbish.

<u>Station 12</u>. (adjacent to Stourbridge Canal, Wordsley, S.O.88 885859)

- stones embedded in sand; fluctuating amounts of rubbish especially bricks; overhanging trees.

<u>Station 58</u>. (u/s discharge from Roundhill S.T.W., Whittington, S.O.88 852828)

- irregular, pitted stones embedded in sand, size range 2-5 cms.

<u>Station 59</u>. (west of Kinver S.T.W., Whittington, S.O.88 852824)

- smooth pebbles resting on pebbles embedded in sand, size range 2-5 cms; stone and sand bank in the middle of river; sewage fungus found occasionally but not extensively.

Illey Brook

Station 13. (d/s Illey Lane S.O.98 974821)

- stones and rocks embedded in sand; patches of loose stones; rocks recruited from crumbling bank; size range 2-30 cms.

Station 14. (d/s discharge from Hunnington S.T.W. S.O.98 975823)

- smooth, loose stones on stones embedded in sand; increased sand at times of low flow; sewage fungus from June 1967 to March 1970.

Station 15. (u/s Halesowen Way, Halesowen, S.O.98 971833

- stony with much rubbish at times; sewage fungus at times during period from March 1968 - December 1969.

Lutley Gutter

Station 16. (Brookside Close, Hasbury, Halesowen S.O.98 948834)

- stones (av. 2 cm.) embedded in sand; silty due to blockage March 1973.

Station 17. (Lutley Mill Road, Hasbury, Halesowen S.O.98 949838)

- stones embedded in sand; increased sand at low flows.

Station 18. (Bellevale, Halesowen S.O.98 952844)

- stones embedded in sand; some rubbish and bricks at times.

Mousesweet Brook

Station 20. (Warwick Road, Darby End, Dudley S.O.98 955872)

- stony and silty often with rubbish; adjacent marshland drains to the brook.

Station 21. (Molyneux Road, Bowling Green, Dudley S.O.98 952868)

- stony and sandy, frequently with much rubbish.

<u>Station 22</u>. (u/s Cradley Road, Newtown, Dudley S.0.98 946864)

- stony with bricks and rubbish.

<u>Station 24</u>. (east of Woodland Avenue, Quarry Bank, Dudley S.0.98 936859)

- stony with patches of clay; rubbish sometimes; overhanging trees.

<u>Saltwells Brook</u>

<u>Station 23</u>. (Saltwells Wood, Dudley S.0.98 931868)

- stony, sandy and silty, with areas of bedrock just upstream; rubbish often present.

<u>Black Brook</u>

<u>Station 51</u>. (u/s confluence with Saltwells Brook, Dudley S.0.98 934869)

- stony and silty, with bedrock just upstream; overhanging trees.

<u>Station 52</u>. (d/s confluence with Saltwells Brook, Dudley S.0.98 934868)

- stony and sandy, with bricks from collapsing culvert; overhanging trees.

<u>Ludgbridge Brook</u>

<u>Station 25</u>. (Spring Street, Wollescote, Stourbridge S.0.98 920838)

- smooth, rounded stones embedded in sand.

<u>Wordsley Brook</u>

<u>Station 26</u>. (u/s discharge from Richard Thomas & Baldwins Ltd., Brockmoor, Dudley S.0.98 902874)

- nature of substratum fluctuated greatly, depending upon extent of plant growth downstream, from stony to deep silt.

<u>Station 27</u>. (d/s discharge from Richard Thomas & Baldwins Ltd., Dudley, S.0.98 902873)

- stony with some silt and usually with iron deposits.

Station 28. (Meadowfield Close, Wordsley.
S.O.88 890865)

- stony with sand or silt or iron deposits;
rubbish sometimes present; overhanging trees.

Dawley Brook

Station 55. (d/s Dudley Road, Kingswinford, Dudley.
S.O.88 899892)

- stones (av. size 4 cm.) mostly embedded in sand;
rubbish sometimes present; overhanging trees.

Station 56. (d/s discharge from Pensnett Trading
Estate, Dudley S.O.88 896894)

- stony and silty with iron deposits; overhanging
trees.

Station 29. (d/s Moss Grove, Kingswinford, Dudley.
S.O.88 885894)

- stones embedded in sand, sometimes with gravel,
bricks, silt and rubbish; high, brick wall
adjacent to brook; deeply shaded by wall and trees.

Station 31. (u/s Swindon Road, Wall Heath, Dudley.
S.O.88 874892)

- stony with sand, silt and occasional boulders.

Bob's Brook

Station 49. (d/s of The Dingle, Sedgley, Dudley.
S.O.99 908917)

- smooth, rounded stones embedded in sand and silt;
sometimes with detritus; deciduous woodland.

Station 54. (north of Grafton Gardens, The Straits,
Dudley. S.O.99 908913)

- smooth, rounded stones embedded in sand; overhanging trees and bushes.

Station 32. (d/s Straits Road, Dudley. S.O.99 907912)

- loose stones with silt and bricks; sewage fungus
sometimes present; overhanging trees.

Station 33. (d/s discharge from Lower Gornal S.T.W., Gornalwood, Dudley. S.O.99 901908)

- loose stones and embedded stones with boulders; overhanging trees.

Holbeache Brook

Station 34. (d/s confluence with Bob's Brook, Dudley. S.O.89 898907)

- stony with gravel and with bricks from collapsing culvert; overhanging trees.

Station 35. (u/s Maidens Bridge, Wall Heath, Dudley. S.O.89 879903)

- loose stones resting on stones embedded in sand and silt; usually extensive *Cladophora* cover.

Station 50. (u/s Hinksford Lane, Swindon. S.O.88 868899)

- smooth, loose stones on stones embedded in sand; adjacent farmland.

Penn Brook

Station 36. (u/s discharge from Gospel End S.T.W., Gospel End, Sedgley. S.O.99 905943)

- smooth, rounded stones embedded in sand; size range 1-6 cms; overhanging trees.

Station 37. (d/s discharge from Gospel End S.T.W., Sedgley S.O.99 902943)

- loose stones resting on smooth, rounded stones embedded in sand; size range 1-6 cms; overhanging trees.

Station 38. (d/s Penn Road, Gospel End, S.O.89 898942)

- loose stones and rocks on stones embedded in sand, size range 1-4 cms; overhanging trees.

2.3. Description of the sewage treatment works and features of their operation

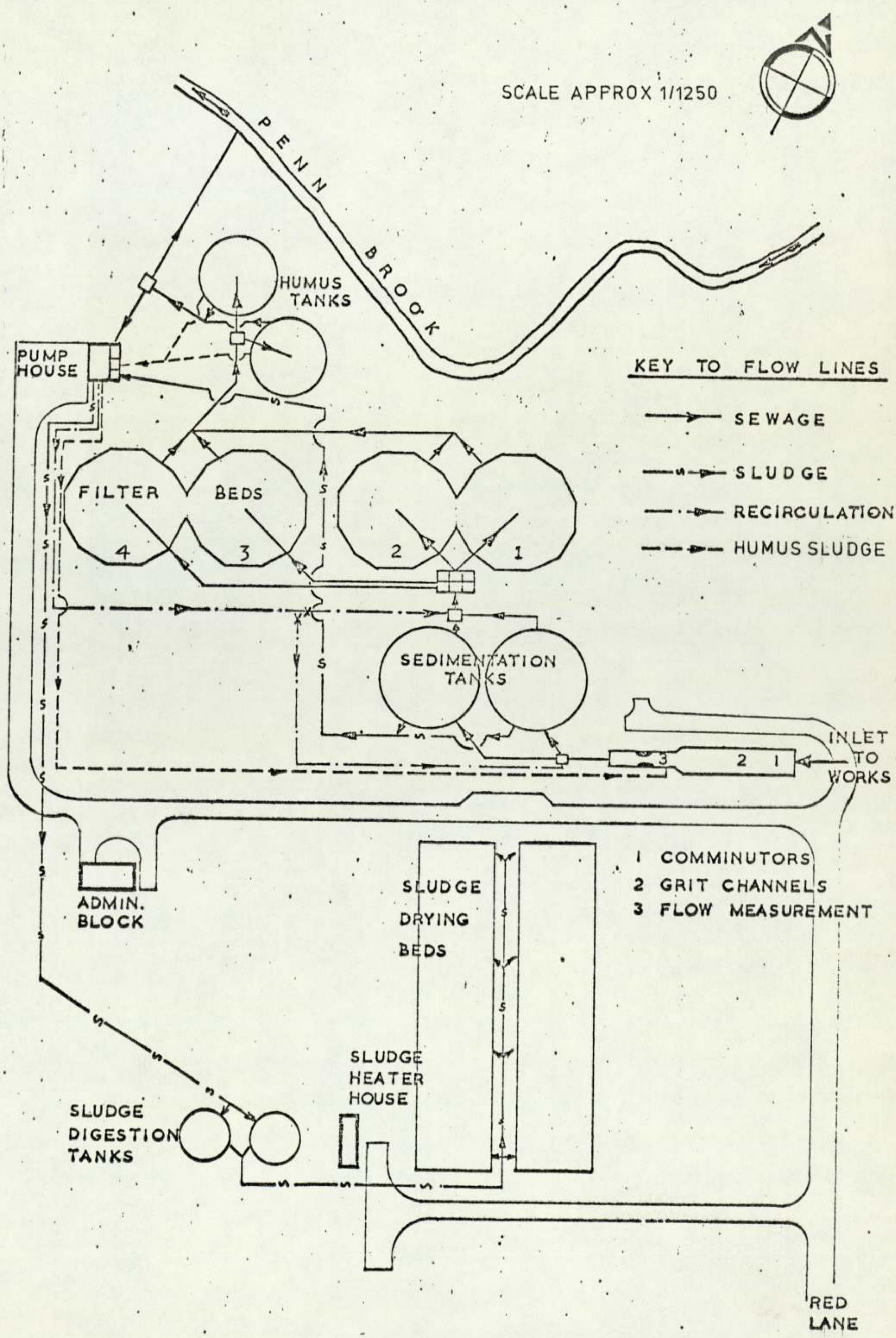
2.3.1. Gospel End Sewage Treatment Works

The new sewage treatment works at Gospel End was designed to treat a dry weather flow (D.W.F.) of (3,409 m^3/d (750,000 gal/d.) and was completed by mid-1967 (Fig. 2.2. page 82).

Crude sewage enters the works via the inlet works, which comprises cominutors, grit channels and a measuring flume. Flow measurements are recorded on an Arkon chart recorder. Unfortunately, the flume measures, in addition to the crude sewage, recirculated humus slude 45 m^3/d (approx. 10,000 gals/d.). From the inlet works the sewage flows to two primary sedimentation tanks each of 1,272 m^3 (280,000 gal.) capacity. There are four twelve-sided percolating filters each 34.7 m (114 ft.) in diameter and with a total capacity of 8,333 yd^3 6371 m^3. The filter medium comprises an upper 1.2m (4 ft.) of 40 mm ($1\frac{1}{2}$ in.) nominal electric furnace slag most of which is rough and angular, but some is pitted, and a lower 0.6m (2 ft.) of 70-100 mm (3-4 in.) medium. Each bed has two pairs of distributor arms, one of each pair taking storm flows. The jets, which have straight unmodified nozzles, are staggered between the two arms and along the length of each arm. Near the perimeter the jets are 19cm. (7.5 in.) apart and near the centre 60-70 cm.(25-30 in.) apart. At 4.5 m (15 ft.) from the perimeter, where the sampling shafts are situated, the jets are 25 cm. (10 in.) apart. The distance of the jets from the media is 15 cm. (6 in.) at the perimeter, 15 cm. at 4.5 m. and 20 cm. near the centre. The frequency of dosing at any particular

consistent, se metric llowed by the imperial equivalent

Fig.2.2. GOSPEL END SEWAGE TREATMENT WORKS - FLOW DIAGRAM



point on the filter is once per revolution. This varies considerably depending upon the flow, so the dosing frequency is extremely variable, from almost stopped to once in less than a minute.

There are two humus tanks, each with a capacity of 568 m^3 (125,000 gal.) from where a combined final effluent is discharged to Penn Brook. The digesters, a primary and a secondary one, have a total capacity of 2463 m^3 (87,000 ft^3) and are open and heated. Digested sludge is run onto drying beds. There is provision for recirculating either filter effluent or humus tank effluent to either the primary settlement tanks or between these tanks and the percolating filters. Humus tank sludge is recirculated to the inlet works for further settlement in the primary settlement tanks. Sludge from these is pumped to the primary digester. The River Authority standards for this new works included not more than 30 mg/l. of suspended solids and a B.O.D. of not more than 20 mg/l.

The former works on this site was capable of dealing with a flow of only 300m^3/d (66,000 g/d) and had, with the considerable development in its drainage area, become overloaded, and so its discharge was polluting the brook. Whilst the new works was being built, sewage was still flowing to the old works and being treated, but as parts of the new works were completed, some of the flow was diverted through these sections. By August 1967, there was little purification in the primary settlement tanks, or in the filters, but there was a 73% reduction in the suspended solids in the humus tanks. During October 1967, good nitrification was being achieved and the final effluent was just in excess of the River Authority limits for B.O.D. and S.S. However, by December 1967, there was appreciable ponding in the two filters being used. Holes were dug in several places in the filters, and it was found that the media was extensively fused ? together by fines.

Despite this, the final effluent was within the River Authority limits during the following summer. Ponding was increasingly noticeable by January 1969, and during the following month a start was made on washing all the media. It was decided to take advantage of this cleaning operation and have sampling shafts inserted into one of the filters. Twelve perforated, rigid P.V.C. shafts were placed in each of the twelve sections of Filter 3, 4.5m (15 ft.) from the perimeter. (See section 3.1). During the operation, two of the filters were being fed with settled sewage. When the cleaning was completed in Filter 3, it was started as one of two filters to be regularly in use. Recirculation was in operation at this time, therefore effluent from the one original filter still in use was used as part of the feed to the cleaned Filter 3. In this way the cleaned filters received an inoculum of organisms from the start of the renewed operation.

Media washing was completed by April 1969, and Filters 1, 2 and 3 were put into operation. During May 1969, a thin, but extensive algal coverage was noticeable on each filter, but, as Fig. 3.1. (page 102) shows, the amount of film was almost non-existent. In addition, the final effluent was becoming increasingly colloidal, so it was suggested that the filter feed be restricted to just two filters. This was done; the film increased and the final effluent became clear. A thick growth of algae was evident on the surface of the two beds in July. At this time, recirculated filter effluent was being introduced before the primary sedimentation tanks.

In March 1970, recirculation was increased to 2:1 ratio and introduced after the sedimentation tanks; also a third bed was brought into operation, ostensibly to combat the increased colloidal nature of the final effluent. Recirculation was reduced to a ratio of 1:1 in October because the final effluent suspended solids were above the River Authority limit. More film accumulated and the suspended solids figures fell to below the limit.

This method of operation continued until October 1972, when humus tank effluent started to be recirculated instead of filter effluent, but recirculation of filter bed effluent recommenced in January 1973, and was introduced after the primary sedimentation tanks. A fourth bed was brought into operation in July. It was found that the distributors on filters 3 and 4 stopped for considerable periods, due to insufficient flow. Frequency of dosing was less due to the extra bed receiving part of the flow. Recirculated filter effluent was introduced directly before the filters at a ratio of 2:1 to overcome this.

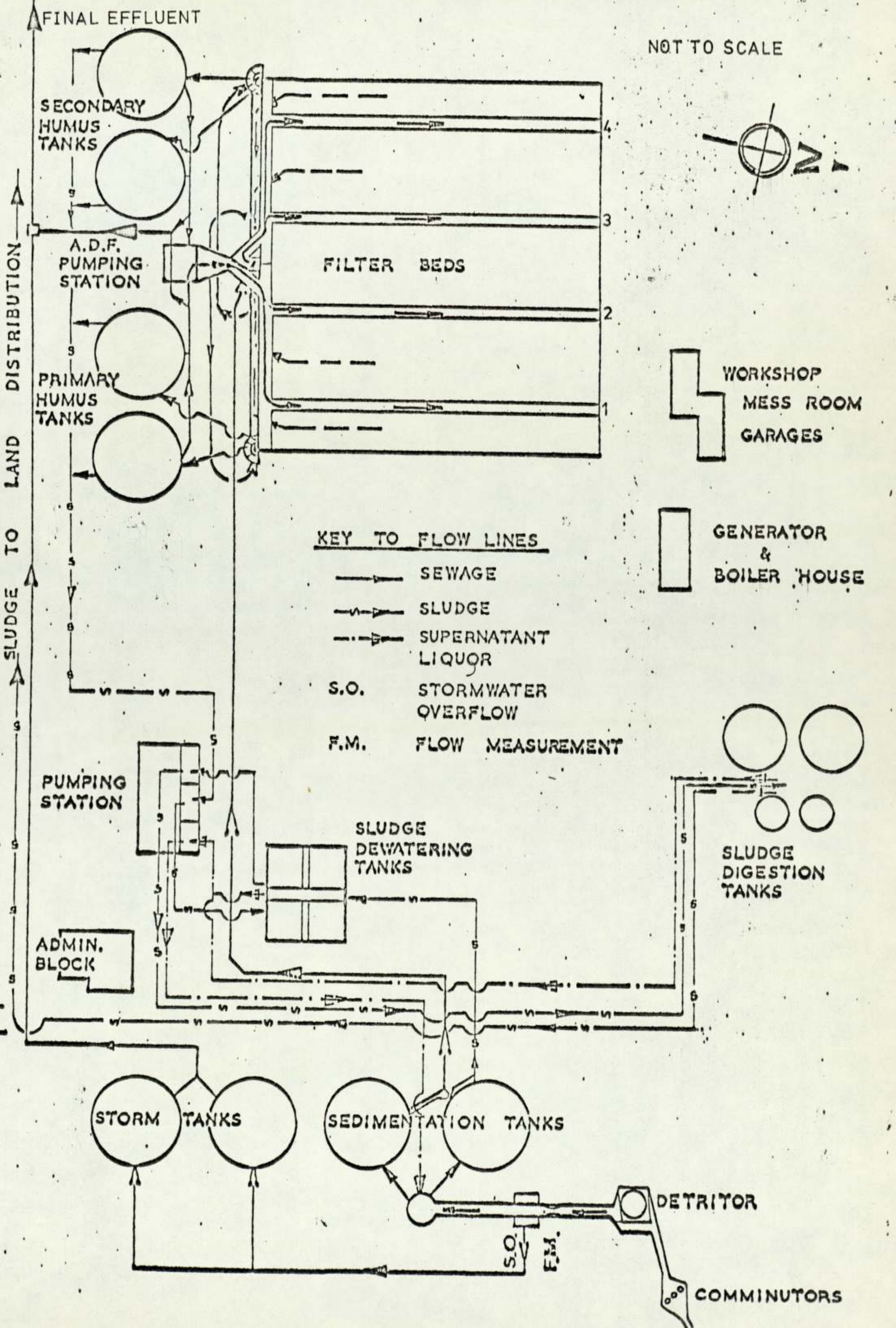
2.3.2. Roundhill Sewage Treatment Works

Treatment of sewage from the Brierley Hill district was formerly by land irrigation at Roundhill Farm, which is situated to the west of Stourbridge. When it was realised, that the discharge to the river resulting from this method of treatment was no longer acceptable, a scheme was put forward to construct a treatment works at Roundhill Farm. This new works started to receive a flow of sewage in January 1972.

The designed D.W.F. was for $17{,}047 m^3/d$ (3.75 m.g.d.) and full treatment can be given to flows up to $51{,}142\ m^3/d$ (11.25 m.g.d.). As the works takes flow not only from Brierley Hill but also from parts of Stourbridge, Kingswinford and Wordsley, the designed D.W.F. was soon exceeded and plans to extend the works by 100% have been proposed. The standards imposed by the former Severn River Authority require, that the effluent contains not more than 30 mg/l suspended solids and 20 mg/l B.O.D.

After passing through the inlet works comprising comminutors and detritors (Fig. 2.3. page 87) the sewage passes to two primary sedimentation tanks, each having a capacity of $2273m^3$ (0.5m.gals.). There are also two storm tanks of the same capacity. The four percolating filters are each 108.8m (357 ft.) long by 30.4m (100 ft.) wide. The medium is 65 mm. ($2\frac{1}{2}$ in.) nominal blast furnace slag with a lower 150 mm. (6 in.) layer of stone medium. The distributor rate of travel can be varied and half of each arm distributes sewage when travelling in one direction and the other half in the reverse

Fig. 2.3. ROUNDHILL SEWAGE TREATMENT WORKS - FLOW DIAGRAM

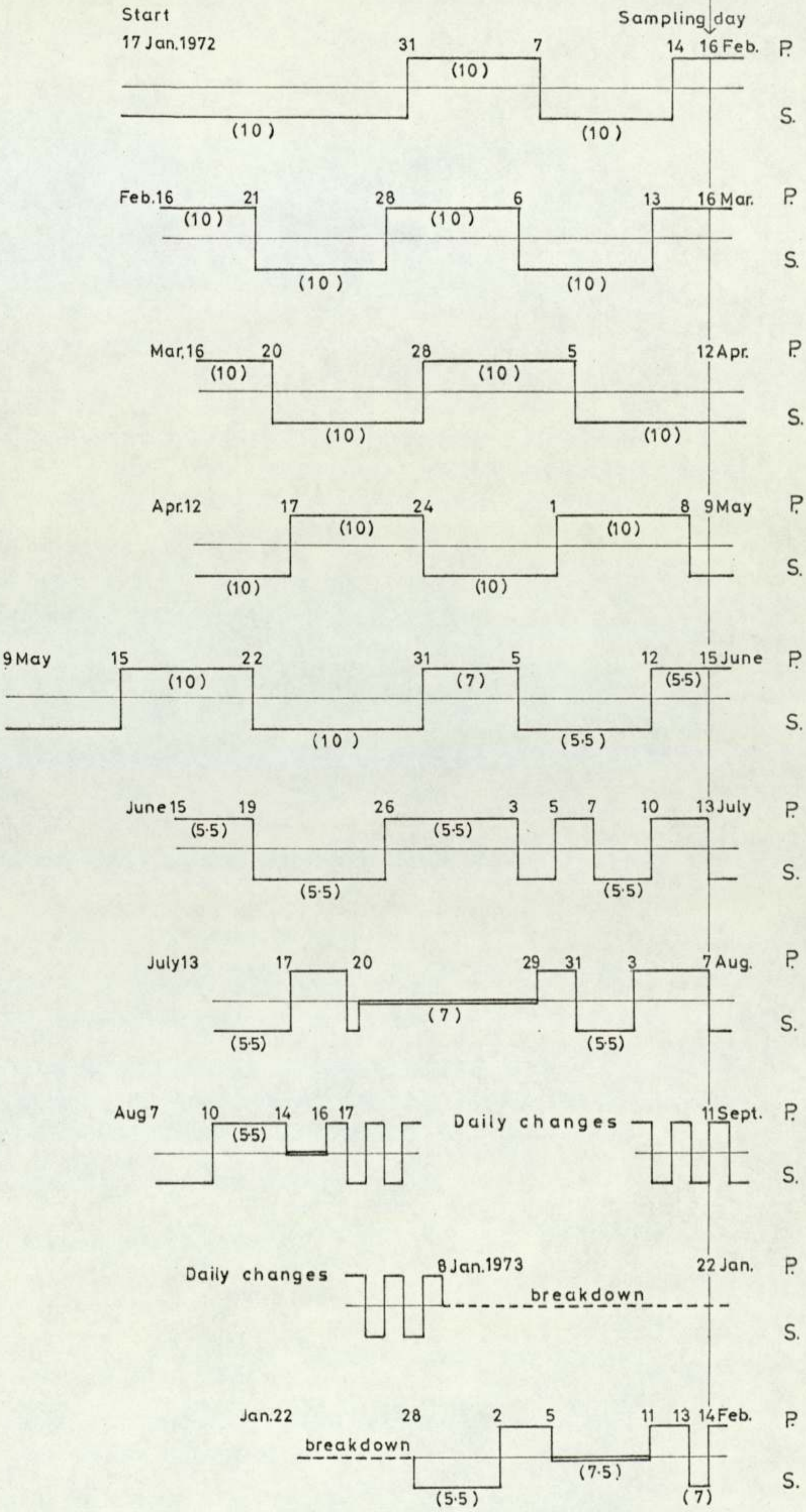


direction. In this way, except at times of high flow, each part of the bed is dosed once per forward/reverse cycle. The filters can be operated as A.D.F., double filtration, or single filtration with or without re-circulation. The distributors are supplied from a central trough by siphoning. The distributor jets are straight, unmodified nozzles placed 7.5 cm. (3 in.) apart and point upwards at an angle of approximately 70°. The four humus tanks each has a capacity of 2,273m^3 (0.5 m. gallons).

There are two heated primary digestion tanks each of 5,682m^3 (1.25 m. gallons) capacity, and with a 30 day retention period. Two unheated secondary digesters have a capacity of 3,410m^3 (0.75 m.gallons) capacity each. Digested sludge is tankered or sprayed onto adjacent farmland. An extension to the works for heat conditioning, filter pressing and incineration of sludge is being constructed.

The first flow of sewage to the works was on January 3rd, 1972 from the Stourbridge area, when filters 3 and 4 were put into operation (see Figs. 2.4. and 2.5. pages 89 & 90). On January 17th, filters 1 and 2 were started. The flow of sewage from the Brierley Hill area commenced on January 25th. The sampling baskets in filters 2 and 3 were first examined in the week of February 14th, that is, about six weeks after the first flow of sewage to filter 3 and four weeks after the first flow to filter 2. Up until the end of January, filters 3 and 4 had been used as the primary filters, but after that time, with the commencement of A.D.F.,

these have not been mentioned before



P=Primary Feed, S=Secondary Feed, (·) Dosing Frequency in minutes.
═══ Total Flow.

Fig.2.4. Roundhill S.T.W. Sequence of Primary & Secondary Feed-Filter 2.

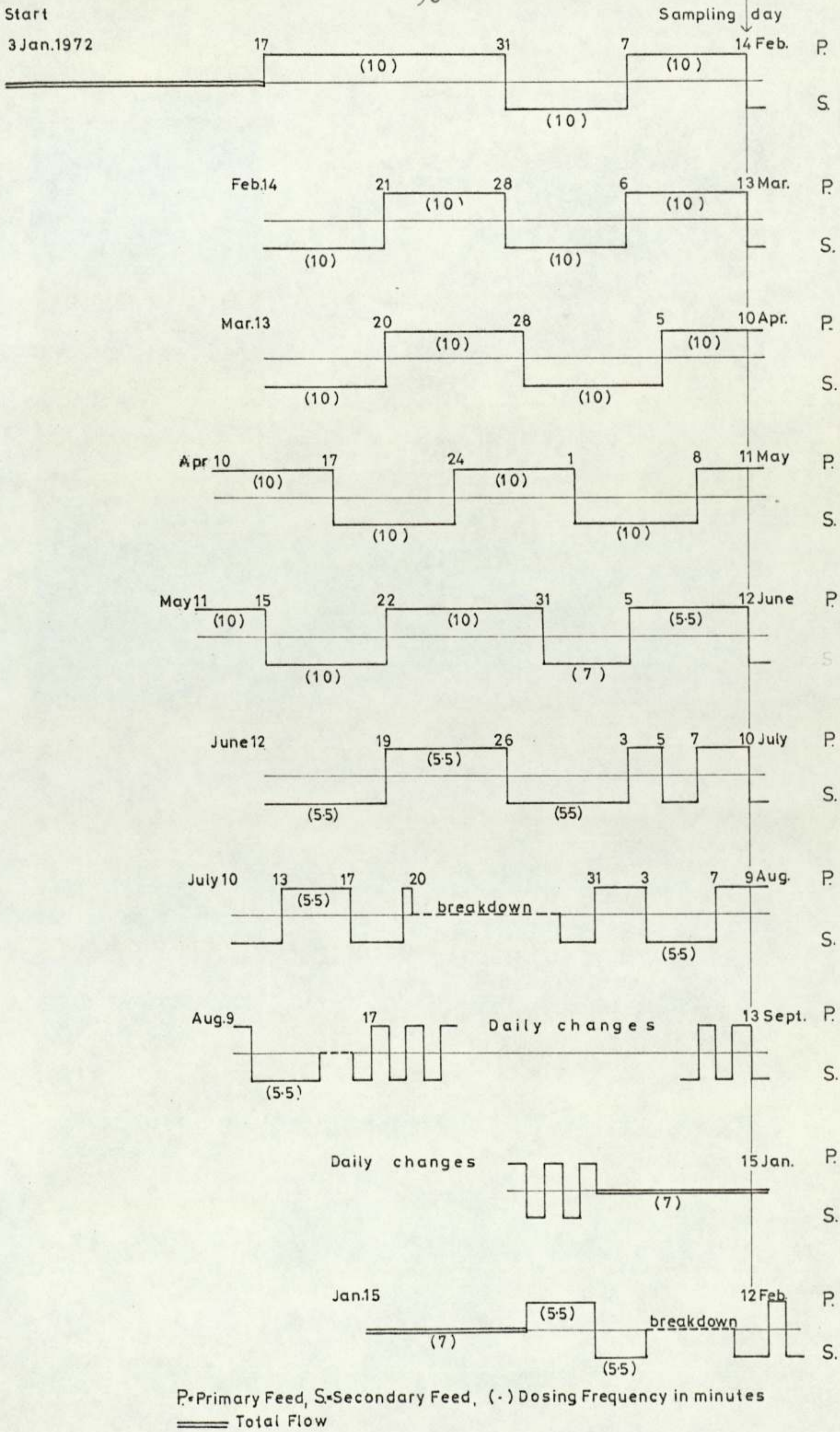


Fig.2.5.Roundhill S.T.W. Sequence of Primary & Secondary Feed - Filter 3.

the sequence of filtration was changed once a week until July, 1972. At the beginning of July, the sequence of filtration was changed every other day, and by the middle of August every day at 9 a.m.

The frequency of dosing, at the beginning of operation in January, was 10 minutes. This was increased to 7 minutes at the end of May and to 5.5 minutes at the beginning of June. Apart from times of breakdown, which were frequent during the winter of 1972/73, this rate was maintained until June 1973, when there was a further increase to a 5.0 minute periodicity. From February 13th 1973, there was a return to an alternate day change over in the filter sequence.

3. Ecological studies on percolating filters

3.1.1. Methods

A number of workers, notably Reynoldson (1947), Hawkes (1965b) and Solbé *et al.*(1967) have used shafts containing baskets or canisters, filled with media and placed in full-scale or pilot-scale percolating filters, in order to study the fauna and film at different depths (see section 1.2.). In most cases these shafts and baskets have been constructed from perforated metal sheet.

In this present study the shafts and baskets were made from perforated rigid P.V.C. piping. The shafts used at the Gospel End works were 1.2 m (4 ft.) deep and had an internal diameter of 15 cm. (5.85 in.). Standing on top of a basal 0.6 m (2 ft.) layer of large media, each shaft contained eight baskets, each of which was 14.8 cm. (5.75 in.) deep and had an external diameter of 14 cm. (5.5. in.) and an internal diameter of 12.6 cm. (5.0 in.). This left a gap between the inner surface of the shaft and the outer surface of the baskets of 0.5 cm. (3/16 in.). Each basket had a capacity of 1,845 cc. There was a brass rod, fixed horizontally near the top, for lifting purposes. There were twelve shafts in the study filter (filter 3) each placed 4.5 m. (15 ft.) from the perimeter.

At the Roundhill works, the shafts were 1.83 m. (6.0 ft.) deep and thus penetrated the whole depth of the filter. Since this works was operated on an A.D.F. system, 24 shafts were used, twelve in each of two filters. Each shaft had an internal diameter of

22.8 cm. (9.0 in.). Each basket was 22.8 cm. (9.0 in.) deep with an external diameter of 21.9 cm. (8.62 in.) and an internal diameter of 20.6 cm. (8.12 in.). Thus, each basket had a capacity of 7,646 cc. cm^3 Between the shaft and the baskets there was a gap of 0.45 cm. A thick plastic tube fitted at the top of each basket was used for lifting. The shafts were situated in three lines of four 2.4 m. (8.0 ft.) apart near the northern end of filters 2 and 3.

Two temperature probes (mercury in steel) were inserted at a depth of 1.2m (4 ft.) and 30 cm. (1 ft.) next to one of the shafts at Gospel End works and were connected to a Rototherm chart recorder. At the Roundhill works, there were two temperature probes, one for each pair of filters, placed at a depth of 30 cm. (1 ft.) and connected to Cambridge chart recorders.

Each month the baskets from one shaft, at Gospel End works, and from two shafts in separate filters, at the Roundhill works, were lifted, using a purpose-made hooked rod. A different shaft was examined each month, so that after sampling each shaft was left undisturbed for a further twelve months. The contents of each basket was placed separately, in turn, in a rotary washer, as described by Hawkes (1965b), but made of perforated rigid P.V.C. Two or three litres of water were poured into the washer and the media was washed until all of the film had been removed. The washed media was replaced in the same basket and the baskets replaced in the original order in the shaft. The film and fauna so removed was drained into large Buchner funnels (24 cm. diam.) containing a Whatman 114 wet-strengthened filter paper and fitted to 2 l. Buchner flasks. The contents were filtered and stirred from time to time to ensure an even spread of material, until dry.

The filter paper and filtered material from each filtration was cut into four or eight equal pieces, depending upon the amount of material (film and fauna) accumulated. One piece (a) was used for the determination of dried solids and volatile solids, another piece (b) for a count of the macroinvertebrates; another piece (c) for a count of microinvertebrates and a fourth piece was retained for future reference.

a. Procedure for the determination of dried solids and volatile solids: the film was washed off each filter paper into large porcelain dishes and placed in an oven at 105°C for 24 hrs. The dishes were cooled and weighed to give the dry weight of solids, including animals. Each dish was then placed in a muffle furnace at 600°C for 1 hr., followed by cooling until ambient. The dishes were weighed to give the weight of non-volatile solids which, subtracted from the weight of the dried solids, gave the weight of volatile solids, including animals. The amount of film was expressed as g. of volatile solids (less animals)/l. of media and was calculated as follows:-

$$\frac{\text{wt. of volatile solids (less animals)} \times 4(8) \times 1000}{\text{vol. of basket}}$$

b. Procedure for macroinvertebrate count. The film was washed off the filter paper into a fine mesh (60 mesh, 250 microns aperture) sieve, where it was washed with tap water to remove very fine solids, and was then put in a white enamel tray. The macroinvertebrates were identified and counted, and then placed in a porcelain crucible. Each crucible was put in an oven for 24 hrs., allowed to cool and weighed. The weight of dried animals was subtracted from the dry weight of solids found in a. to give the dry weight of the film. The crucibles containing the dried animals were then placed in a muffle furnace at 600°C for 1 hr., cooled and weighed. The weight of non-volatile material was subtracted from the weight of the dried animals to give the volatile weight of animals. This could be used for calculating the biomass. It was subtracted from the weight of volatile solids calculated in a. to give the weight of film as volatile solids.

The numbers of macroinvertebrates per litre of media was calculated using a conversion factor determined by the amount of film assessed and the volume of the basket.

c. Procedure for microinvertebrate count. The film was washed off the filter paper into a 2lb. Kilner jar approximately $\frac{2}{3}$ full of water. This was homogenised, in a Silverson sealed-unit laboratory mixer, at a low speed for 30 seconds, which was found sufficient to break up the film without damaging the microorganisms. The homogenised samples were made up to 1 litre, 2 litres, 5 litres or 10 litres in beakers, depending upon the amount of film. A 1 ml. sample was pipetted into a Sedgewick-Rafter counting-cell, divided into 1 mm. squares. The contents was examined under the microscope and the microorganisms identified and counted. The presence of algae, filamentous bacteria or fungi was noted. The numbers of organisms in each species were converted to numbers/g. of film (dry wt.), using the following:-

$$\frac{\text{Nos. of microorganisms counted} \times 10^3 \times \text{dilution vol.(l.)}}{\text{g. of film}}$$

3.1.2. Method of trapping insects emerging from filters

The trap developed by the Water Pollution Research Laboratory (Water Pollution Research, 1964) was used for trapping insects emerging from filters. This consisted of a square frame, 25 cm. x 25 cm., covering an area of $1/16\ m^2$ ($0.062\ m^2$), and was constructed from 'Perspex' and treated wood, A channel, fixed centrally from end to end, distributed the feed to the enclosed area. Resting on the sides of the frame were two pieces of 'Perspex', which sloped down to the channel. The undersides of these pieces were coated with adhesive and placed on the traps for 24 hours each week. The traps were sunk into the surface media to a depth of about 3 in., so as to prevent migration of insects either into or out from the enclosed area. It was possible to utilize only one trap on each filter, so unfortunately no allowance could be made for horizontal variation of insect distribution.

Perhaps!

3.2. Results

Identification of microorganisms and macrofauna was made with the aid of texts by the following authors; Kudo (1966), Curds (1969), Martin (1968), Tomlinson (1946), Smith (1955), Prescott (1954), Coe, Freeman and Mattingly (1950).

3.2.1. Gospel End S.T.W.

There had been reports of ponding in the filters (2.3.1.) at Gospel End during 1967 and 1968, so investigations of film and fauna had been made before the regular sampling programme iniated by this study. Briefly, these investigations showed, that there was a reduced fauna in the ponded areas compared with the non-ponded areas of the filters. Although it was subsequently found, that ponding was due primarily to the accumulation of fines within the filters, a predominance of fungi was also found in the ponded areas. A number of red Chironomus larvae were found in the ponded areas. Enchytraeid worms and Metriocnemus sp. larvae were predominant in the non-ponded areas. Species of nematodes, Stylonychia and Vorticella microstoma were found in both areas. In the summer of 1968 species of Arcella, Colpoda, Psychoda and Cyclops were found. Immediately prior to the cleaning of the study filter, numbers of Metriocnemus larvae, Enchytraeid worms and Psychoda larvae were found in the surface layers.

As explained in section 2.3.1., whilst each filter was being cleaned, two other filters received settled sewage and recirculated filter-effluent. After the study filter had been cleaned it, in turn, became one of the two to receive this flow and so colonization was facilitated by a feed, containing some of the fauna which had already established itself in an operational filter. Nevertheless, a definite sequence of colonization and stabilization of different species was discernible during the first few months of operation. (Figs. 3.1. and 3.6.).

Some organisms such as Stylonychia sp., Colpoda sp., Paramecium sp. and rotifer spp. showed large initial populations but were soon superceded and appeared later only in small numbers. The first samples were taken in April 1969, i.e. one month after the start of filter operation, when it was found that the microfauna was dominated by Stylonychia sp. at the surface. The fauna comprised mostly Vorticella microstoma, Stylonychia sp., nematodes, Colpoda sp. and Paramecium sp. at lower levels. Nematodes were particularly abundant in May (Fig. 3.1.), when Opercularia coarctata, Paramecium sp. and Stylonychia sp. were also present. Carchesium polypinum was found in isolated, large numbers in June, but not throughout the filter. Nematodes and Paramecium were dominant in June, but by July 1969 Vorticella convallaria had appeared and become dominant and rotifers (Rotaria sp.) had also appeared in appreciable numbers. An equally sudden influx and increase made Opercularia coarctata the dominant species in August (Fig. 3.1.), though nematodes and Vorticella convallaria were still common. Vorticella convallaria had regained its dominance by September and Carchesium polypinum was again abundant. During subsequent months there was a more even distribution between nematodes and Vorticella convallaria, though by March 1970 Carchesium polypinum became abundant and dominant (Fig. 3.1.).

A few larvae of the chironomid Metriocnemus hirticollis were found in the first month of sampling (April 1969). No other species of macroinvertebrate was found until June, when a sudden increase in numbers of Metriocnemus coincided with the appearance in large numbers of Limnophyes minimus (= Hydrobaenus minimus = Spaniotoma minima) larvae (Fig. 3.6.). Psychoda larvae also appeared in fairly large numbers in the lower part of the column. Enchytraeid worms, Lumbricillus (rivalis?) were not found until July, and then only in small numbers. Another large number of Limnophyes larvae appeared in September and October. Psychoda larvae and Enchytraeid worms showed steady increases during the following months, but Metriocnemus larvae remained few in number until February 1970. Lumbricid worms first occurred in September (Fig. 3.6.), but were subsequently found in only small numbers. Other fauna occurred spasmodically and included Staphylinid beetles, mites, Muscid Dipteran larvae, Daphnia sp., Naid worms, and from August 1969, sometimes in large numbers, Hypogastrura.

Thus, all the species of microorganisms, which were to be the most abundant in subsequent years, had appeared by the fourth month after the filter started operating (See Table 3.1.). Only five additional

Table 3.1.

Microinvertebrates found in the study filter at Gospel End S.T.W.

(Filter started - March 1969)

First sampled

Microorganisms	? First Occurrence	Microorganisms	First Occurrence
Stylonychia sp.	4/69	Aelosoma hemprichii	7/69
Nematode spp.	4/69	Trachelophyllum sp.	8/69
Vorticella microstoma	4/69	Stentor sp.	8/69
Colpoda sp.	4/69	Spirostomum sp.	8/69
Paramecium caudatum	4/69	Arcella sp.	8/69
Ileonema sp.	4/69	Chilodonella sp.	9/69
Euplotes sp.	4/69	Acineta sp.	11/69
Opercularia coarctata	5/69	Hemiophrys fusidens	12/69
Colpidium sp.	5/69	Hemiophrys pleurosigma	1/70
Litonotus sp.	5/69	Amphileptus sp.	1/70
Rotaria sp.	5/69	Podophrya sp.	7/70
Encentrum sp.	5/69	Tardigrade sp.	12/70
Amoeba proteus	5/69	Tokophyra sp.	6/71
Carchesium polypinum	6/69	Opercularia minima	7/71
Aspidisca costata	6/69	Amoeba radiosa	7/71
Vorticella convallaria	7/69		

species were found after January 1970. Most of the macroinvertebrate species had also appeared by the fourth month, except for lumbricid worms, which were found after six months of operation, and larvae of <u>Orthocladius rhyacobius</u> after twenty months of operation.

The monthly vertical distribution of film, micro-fauna and macrofauna is shown in Figs. 3.1. to 3.10. The temperature of the filter feed is shown also; no appreciable difference was discernible between the average recordings of temperatures in the upper foot and at the four foot level. The histograms for the amount of film (as volatile solids) present show, that the maximum film accumulation occurred during the colder months of each year. Increased accumulation was usually first evident in November, with maximum accumulations between December and February (Figs. 3.1. to 3.5.). Although occasional temperatures of 2° or 3°C were recorded some nights, the minimum weekly mean temperatures were rarely below 5°C. There were often marked reductions in the amounts of film by March with the increases in temperature, though in 1973 this reduction did not occur until May (Fig. 3.5.), despite a general rise in temperature from the middle of March onwards. Much of the film accumulation occurred in the top 30 cm., though in the colder months there was considerable accumulation also at lower levels. During the period December 1973 to February 1974, there was a greater accumulation of film in the lower parts of the filter than in the upper parts (Fig. 3.5.).

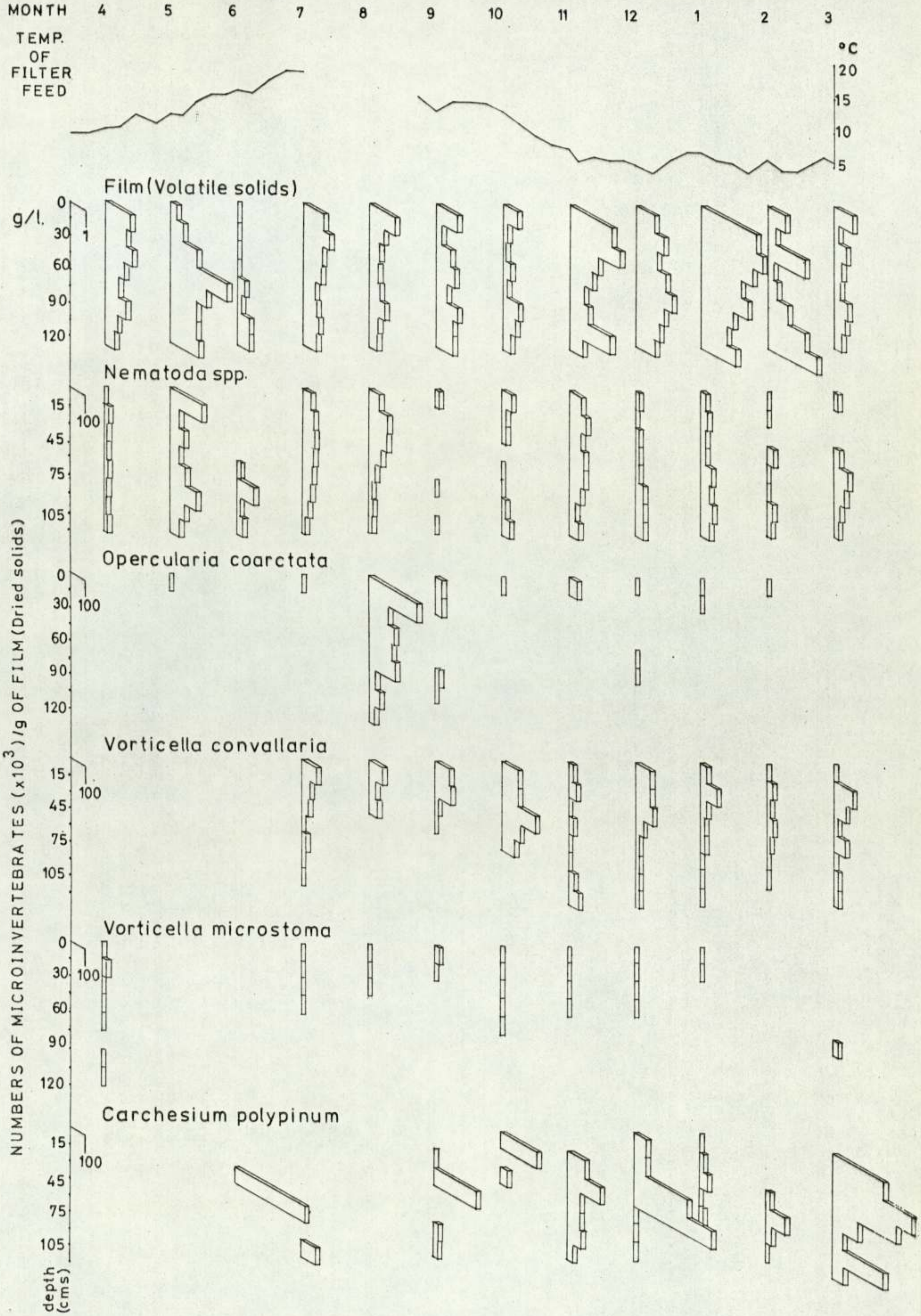


FIG. 3.1. VERTICAL DISTRIBUTION OF FILM AND MICROINVERTEBRATES.
GOSPEL END S.T.W. 1969-1970.

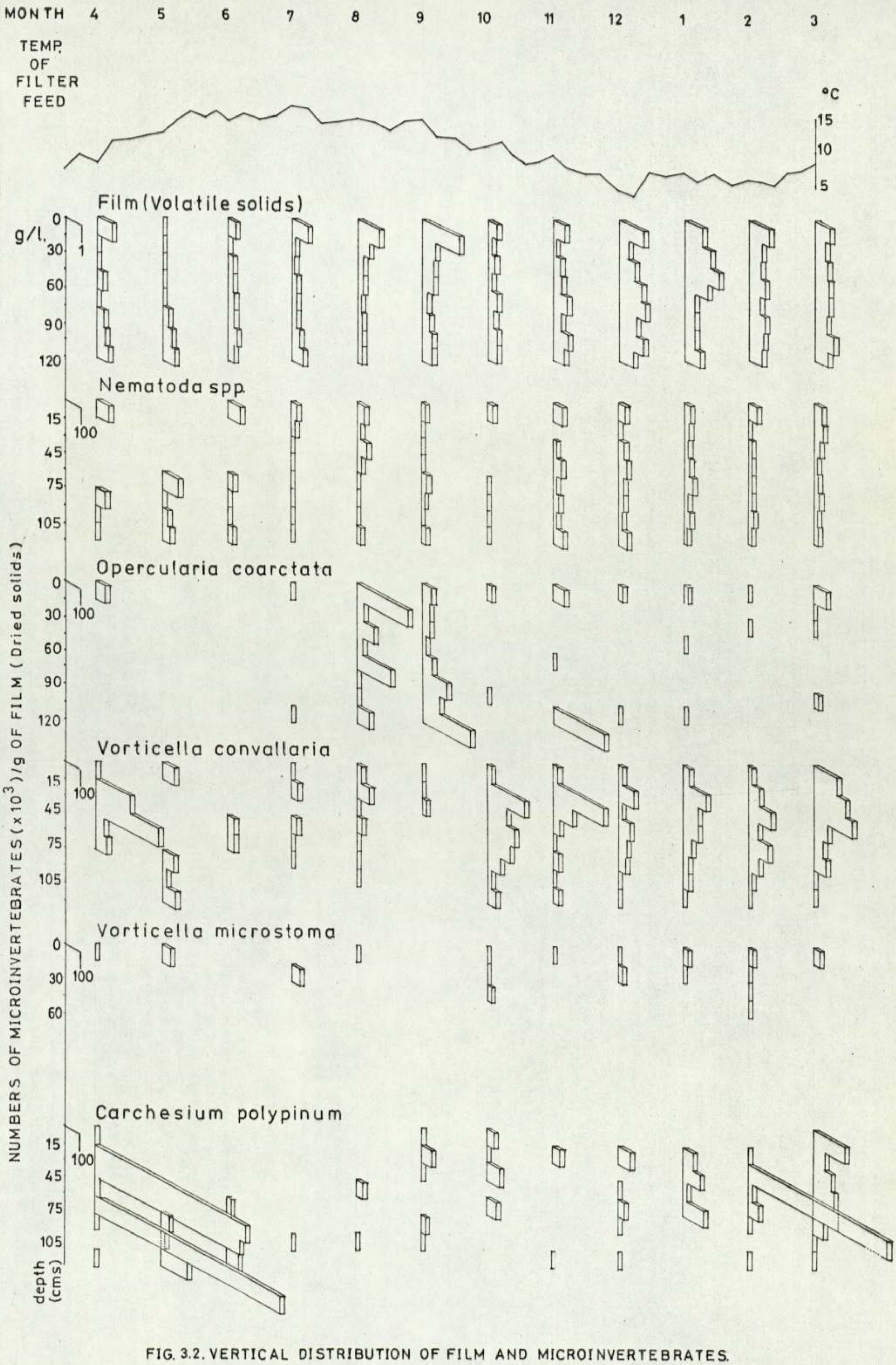


FIG. 3.2. VERTICAL DISTRIBUTION OF FILM AND MICROINVERTEBRATES.

GOSPEL END S.T.W. 1970-1971.

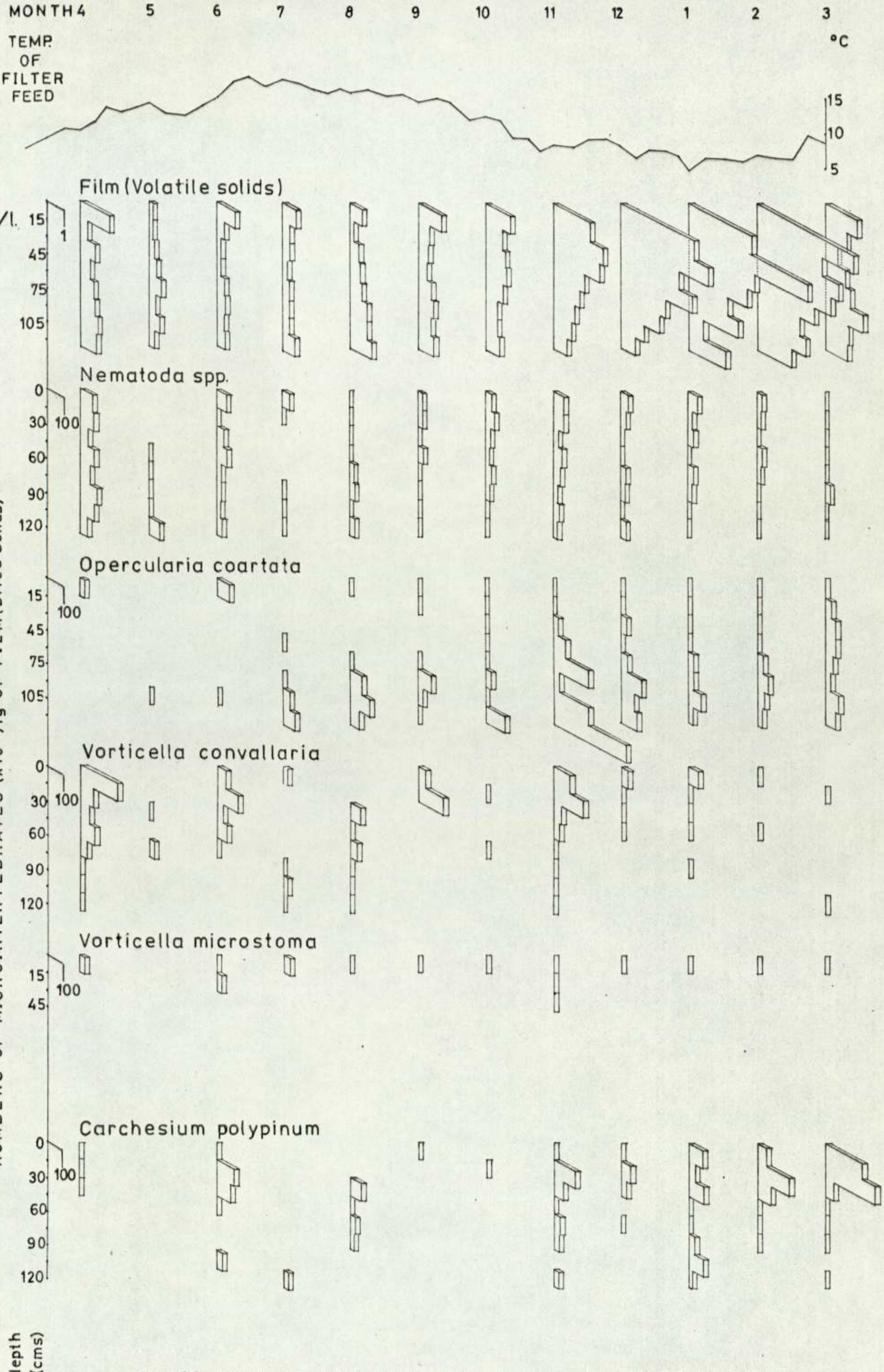


FIG. 3.3. VERTICAL DISTRIBUTION OF FILM AND MICROINVERTEBRATES.

GOSPEL END S.T.W. 1971-1972.

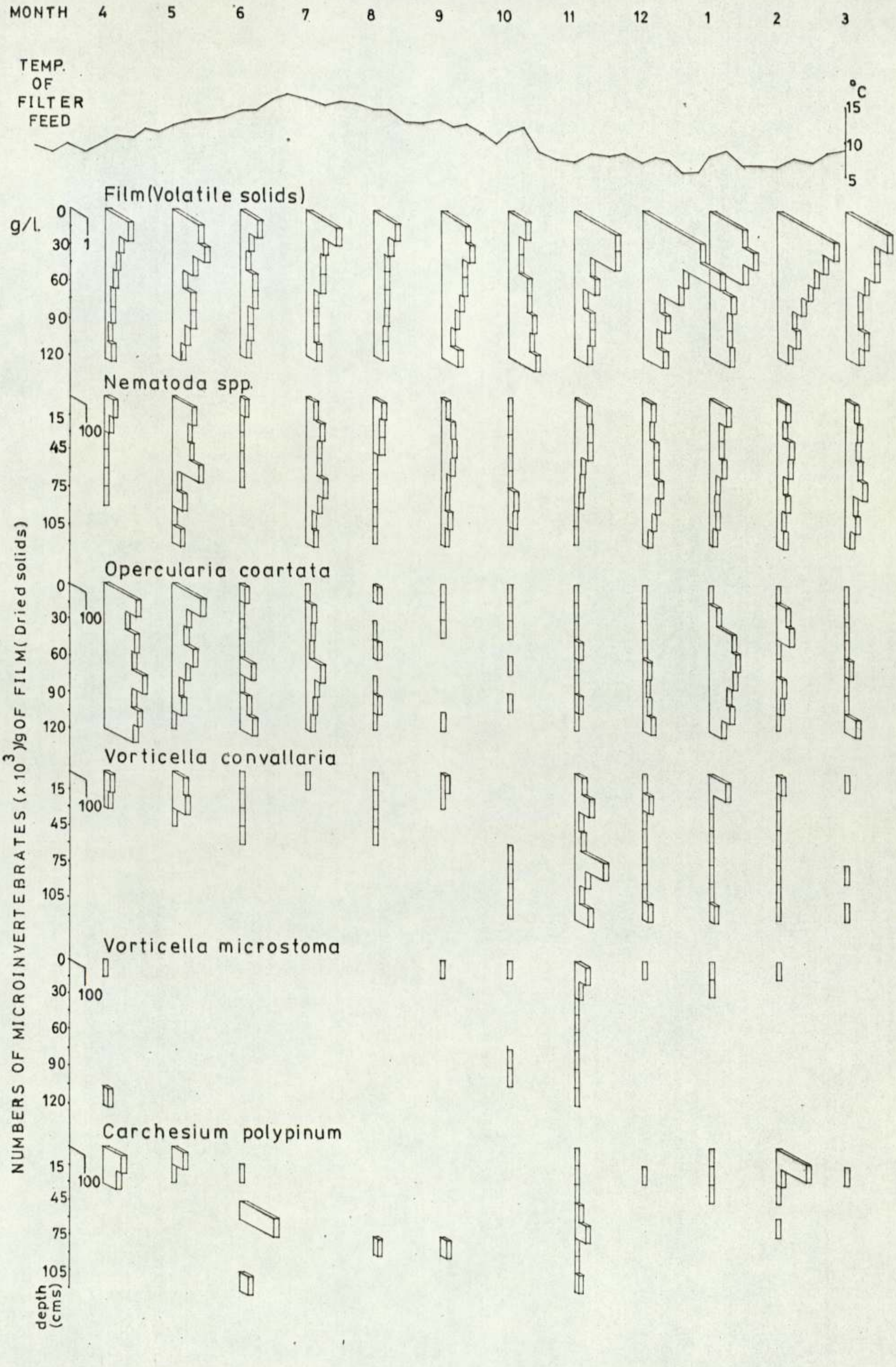


FIG. 3.4. VERTICAL DISTRIBUTION OF FILM AND MICROINVERTEBRATES, GOSPEL END S.T.W. 1972-1973.

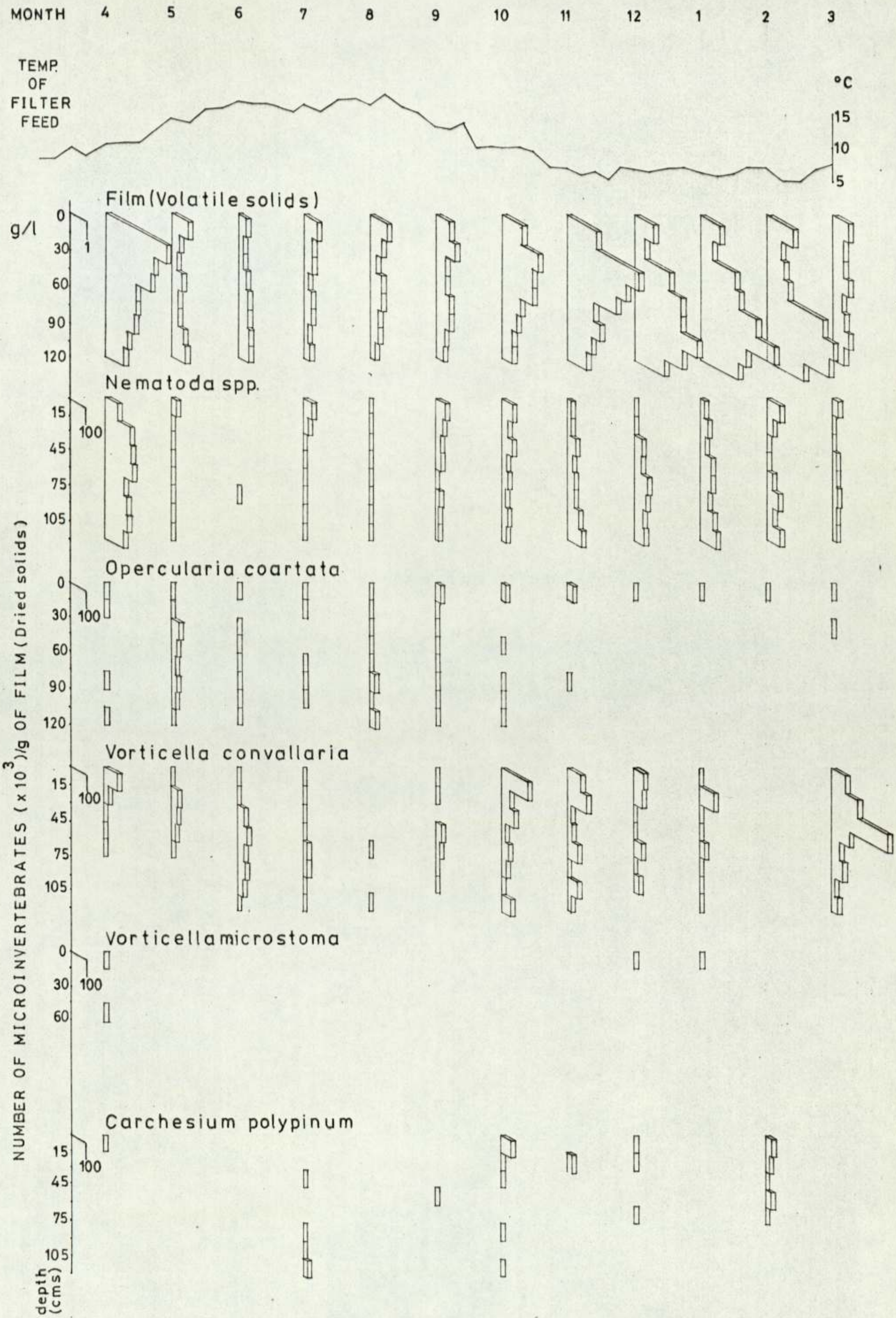


FIG. 3.5. VERTICAL DISTRIBUTION OF FILM AND MICROINVERTEBRATES.

GOSPEL END S.T.W. 1973-1974.

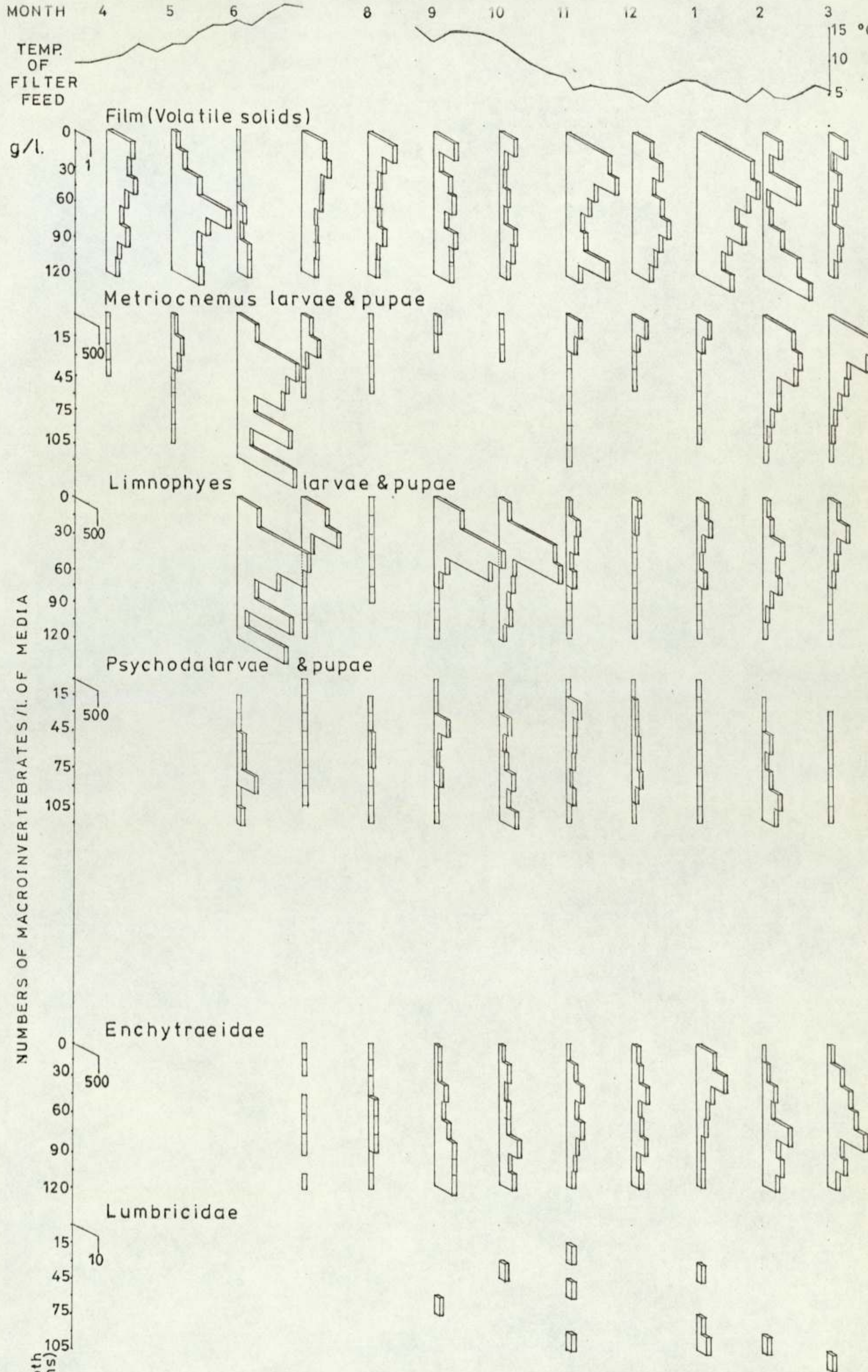


FIG. 3.6. VERTICAL DISTRIBUTION OF FILM AND MACROINVERTEBRATES.
GOSPEL END S.T.W. 1969-1970.

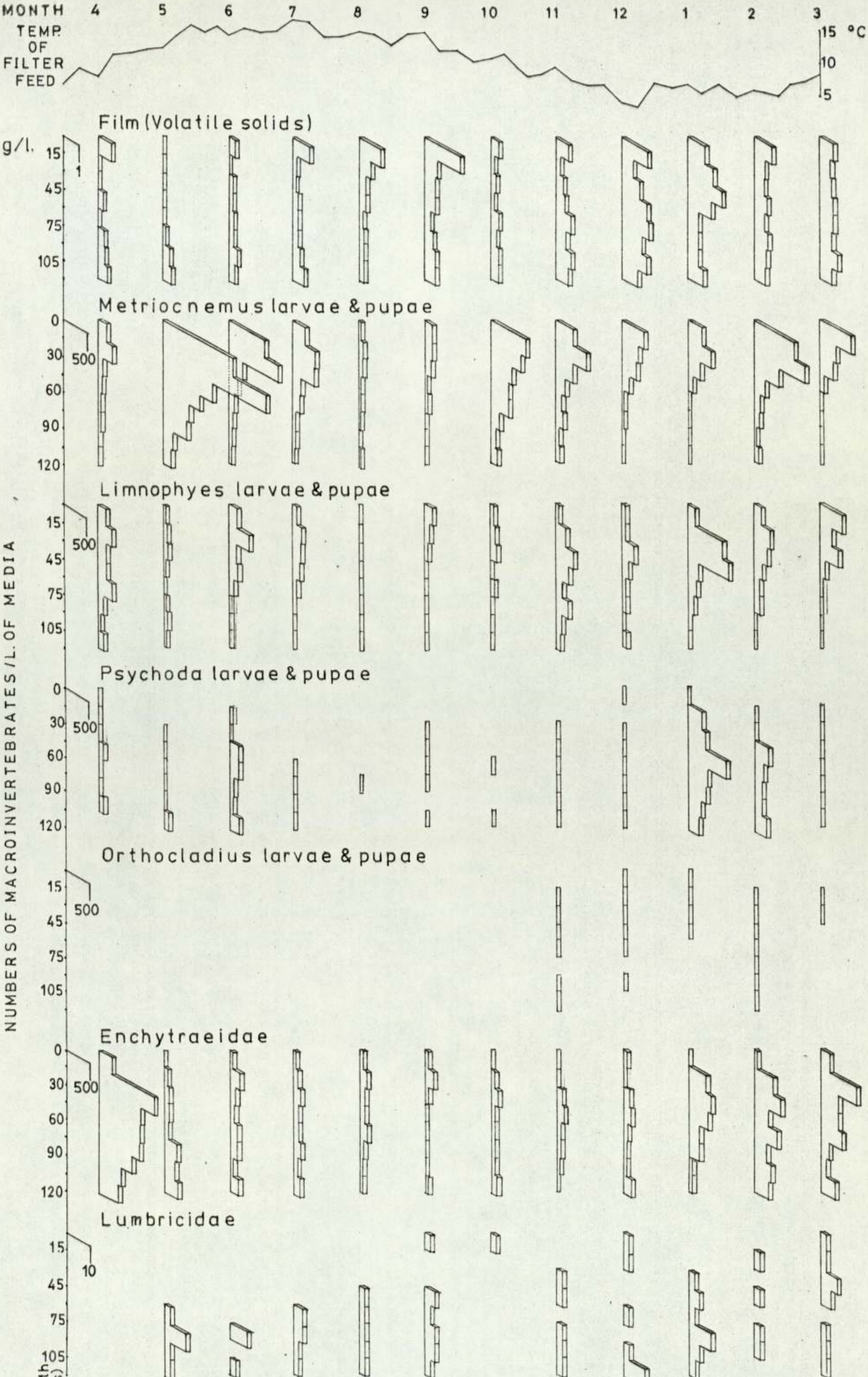


FIG. 3.7. VERTICAL DISTRIBUTION OF FILM AND MACROINVERTEBRATES. GOSPEL END S.T.W. 1970-1971.

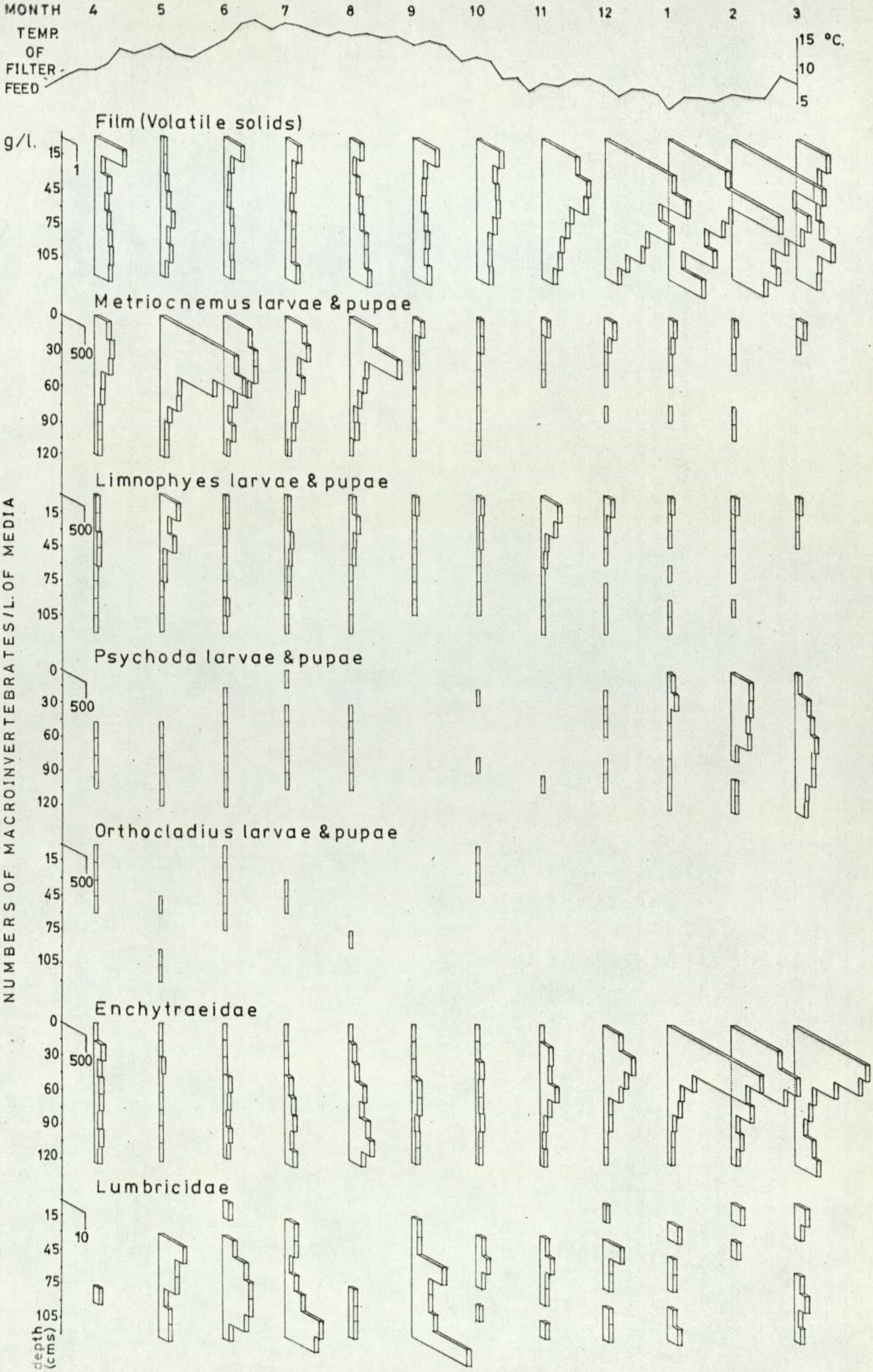


FIG. 3.8. VERTICAL DISTRIBUTION OF FILM AND MACROINVERTEBRATES, GOSPEL END S.T.W. 1971-1972.

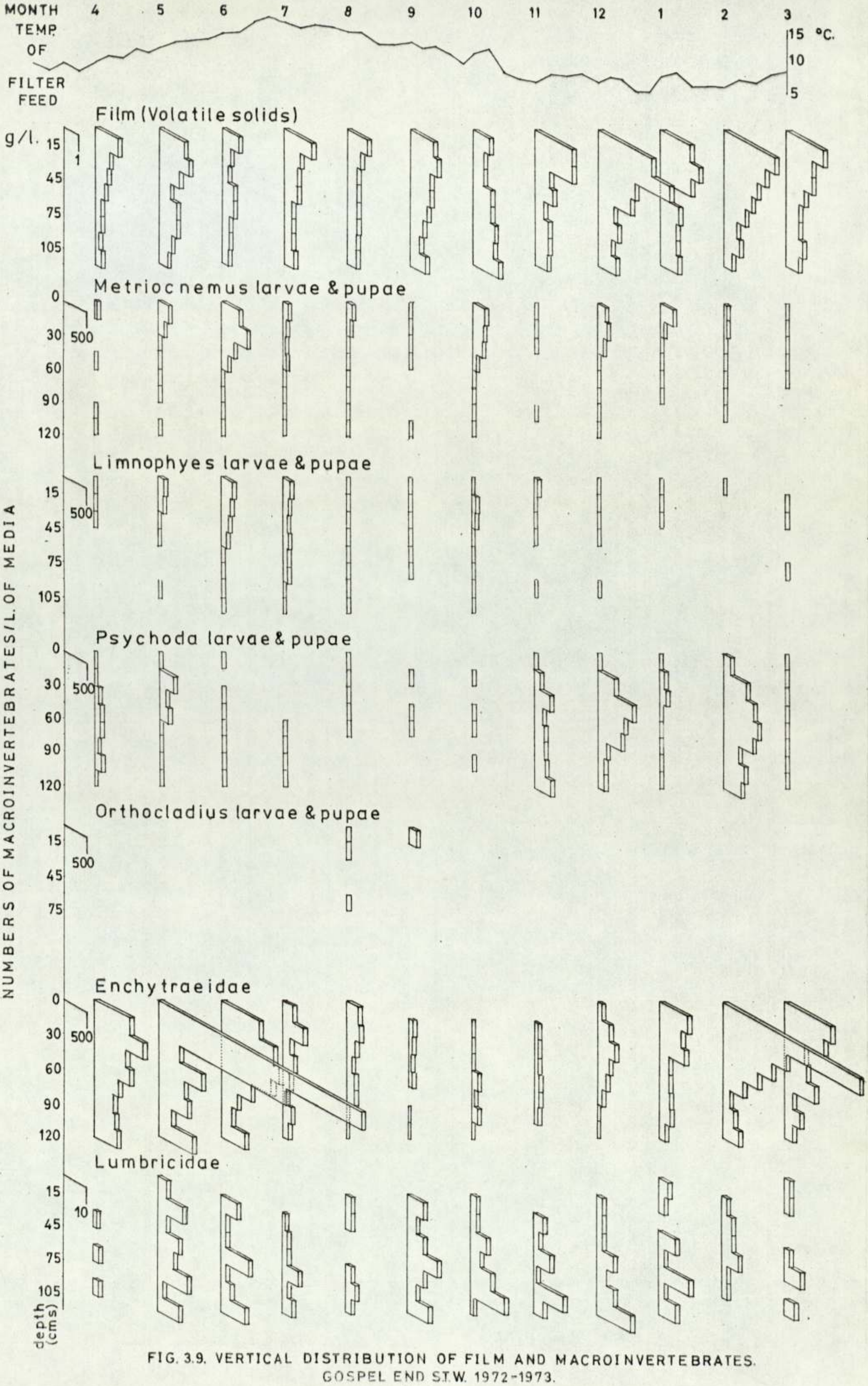


FIG. 3.9. VERTICAL DISTRIBUTION OF FILM AND MACROINVERTEBRATES. GOSPEL END S.T.W. 1972-1973.

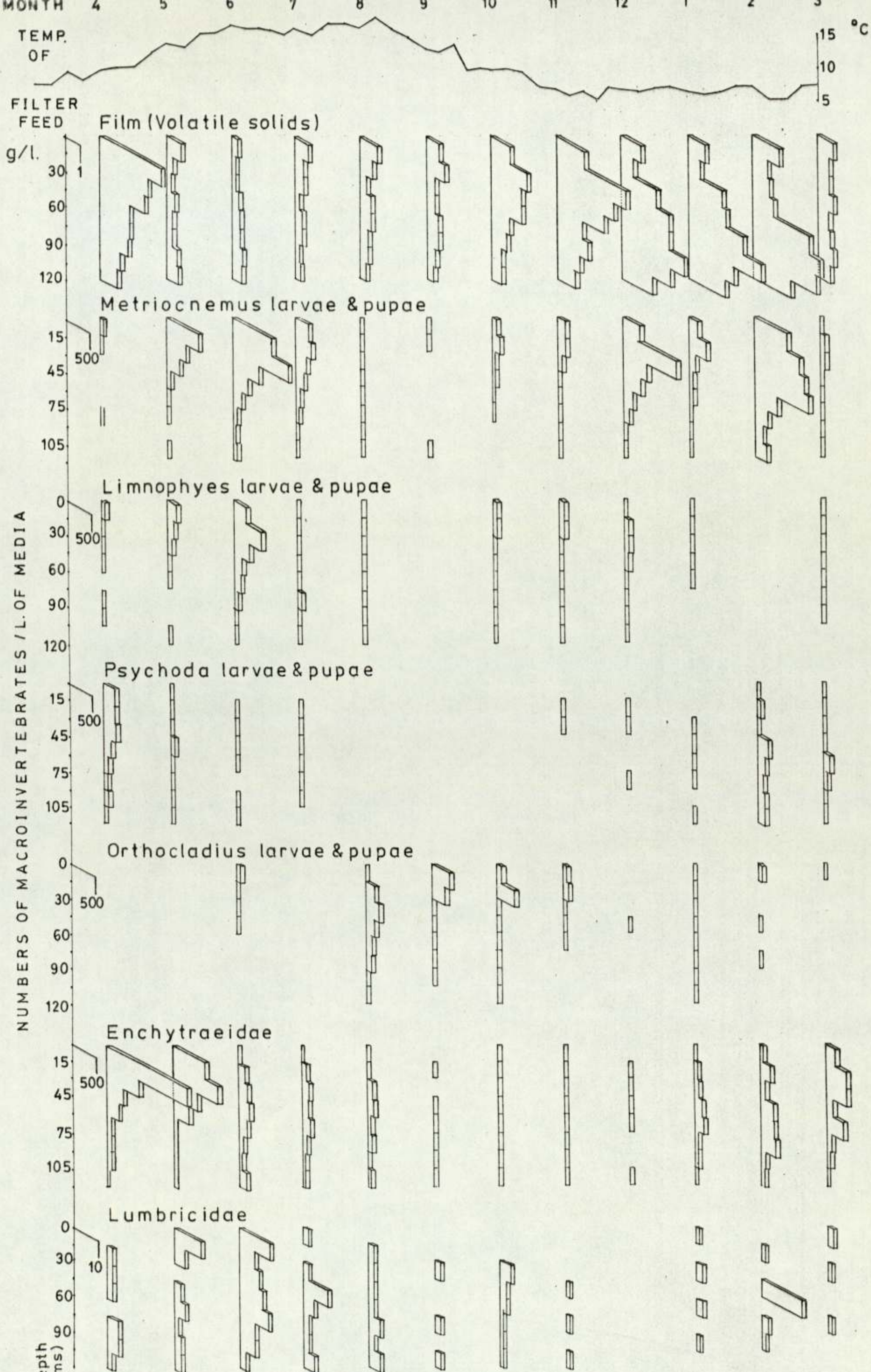


FIG. 3.10. VERTICAL DISTRIBUTION OF FILM AND MACROINVERTEBRATES. GOSPEL END S.T.W. 1973-1974.

In the surface layers during the first month of sampling, a species of diatom, Navicula, was present in large numbers, together with some Chlorococcus sp. and Zoogloea sp. Filamentous bacteria were not evident until the following month, when they were found throughout the filter. Stigeoclonium sp. and Phormidium sp. were extensive by July, and Ulothrix sp. was found in August. Some fungal growths were observed during the colder months from December 1969 to February 1970, but these had disappeared by March. Throughout the investigation there were fluctuating populations of filamentous

filamentous bacteria?

bacteria, Zoogloea sp., Stigeoclonium sp., Ulothrix sp., Chlorococcus sp., Phormidium sp. and occasionally some fungi, including predatory forms.

The results of counts of the most consistently found microorganisms are represented in Figs. 3.1. to 3.5. Nematode worms were never found in enormous numbers, though their greater biomass in relation to that of other microorganisms would possibly indicate a greater importance than their numbers relate suggest. The highest number found was 222,000/g. of film (as dried solids) in May 1969. Apart from the early months of colonization, when a number of species were found abundantly for short periods, the most successful protozoan species were various peritrich ciliates, Opercularia coarctata, Vorticella convallaria and Carchesium polypinum. All of the species, however, showed great variation both in monthly abundance and in vertical distribution. The greatest numbers of Opercularia coarctata were recorded both at the surface (349,000/g. in August 1970; Fig. 3.2.), and at the lowest level (480,000/g. in November 1971; Fig. 3.3.). During the first two years, there was a distinct pattern of distribution of Opercularia during the year. Very few were found from April to July, but in August there was a sudden increase, followed by a decline in September, rapid in 1969 (Fig. 3.1.) but less so in 1970 (Fig. 3.2.), to very small numbers again. This pattern was not obvious in subsequent years, when there was a more even distribution from month to month.

The most noticeable pattern in the distribution of Vorticella convallaria was its tendency to be confined mostly to the upper half of the filter. It was much more abundant in the colder months, but the peak abundance did not re-occur in the same month each year. The greatest number occurred in April 1970 (Fig. 3.2.), when 412,000 were estimated. Despite being the only peritrich found in the first month of sampling, Vorticella microstoma was never found in substantial numbers, and became even less frequently found towards the end of the investigation. The distribution of Carchesium polypinum was extremely variable both in its vertical location in the filter and in its monthly occurrence. This was possibly due to its colonial habit, large numbers being found isolated together. The greatest abundance was found in April 1970, when a count of 1,287,000/g. of film was recorded.

In contrast, distinct patterns were discernible in the distribution of most of the regularly occurring macroinvertebrate species. In June 1969, Metriocnemus larvae and pupae were abundant throughout the filter, but thereafter they were usually much more abundant in the upper part of the filter (Figs. 3.11. to 3.15.). Peaks of differing magnitude usually occurred over a two month period, the principal one being May to June, but a lesser peak also occurred in February to March, though this peak was missing both in 1972 and in 1973. The greater peak was extended in 1971-72 through to the end of August. Minor peaks occurred in August 1971 (Fig. 3.8.), October 1970 (Fig. 3.7.) and December 1973 (Fig. 3.10.). The highest mean number of larvae and pupae in the column was 859/l. of media in May 1970 and 1,865/l. in the top 30 cm. in the same month (Fig. 3.7.). The level at which the greatest abundance of larvae and pupae occurred was usually that between 15 and 30 cm. However, mean numbers/column were as little as 2 in some months (e.g. November 1972). An extensive period of comparatively small numbers of Metriocnemus occurred between September 1971 and April 1973 (Figs. 3.8. to 3.10.).

The larvae and pupae of Limnophyes minimus were most numerous during some of the periods when Metriocnemus was also most abundant (Figs. 3.6. - 3.10 and 3.11 - 3.15.). Their greatest abundance occurred, near the beginning of the operation of the filter, in June 1969, which coincided with a sudden increase of Metriocnemus (Fig. 3.6.). A second peak was found during September to October of the same year. In subsequent years, relatively minor increases occurred during January to March 1971 (Fig. 3.7.), May and November 1971 (Fig. 3.8.),

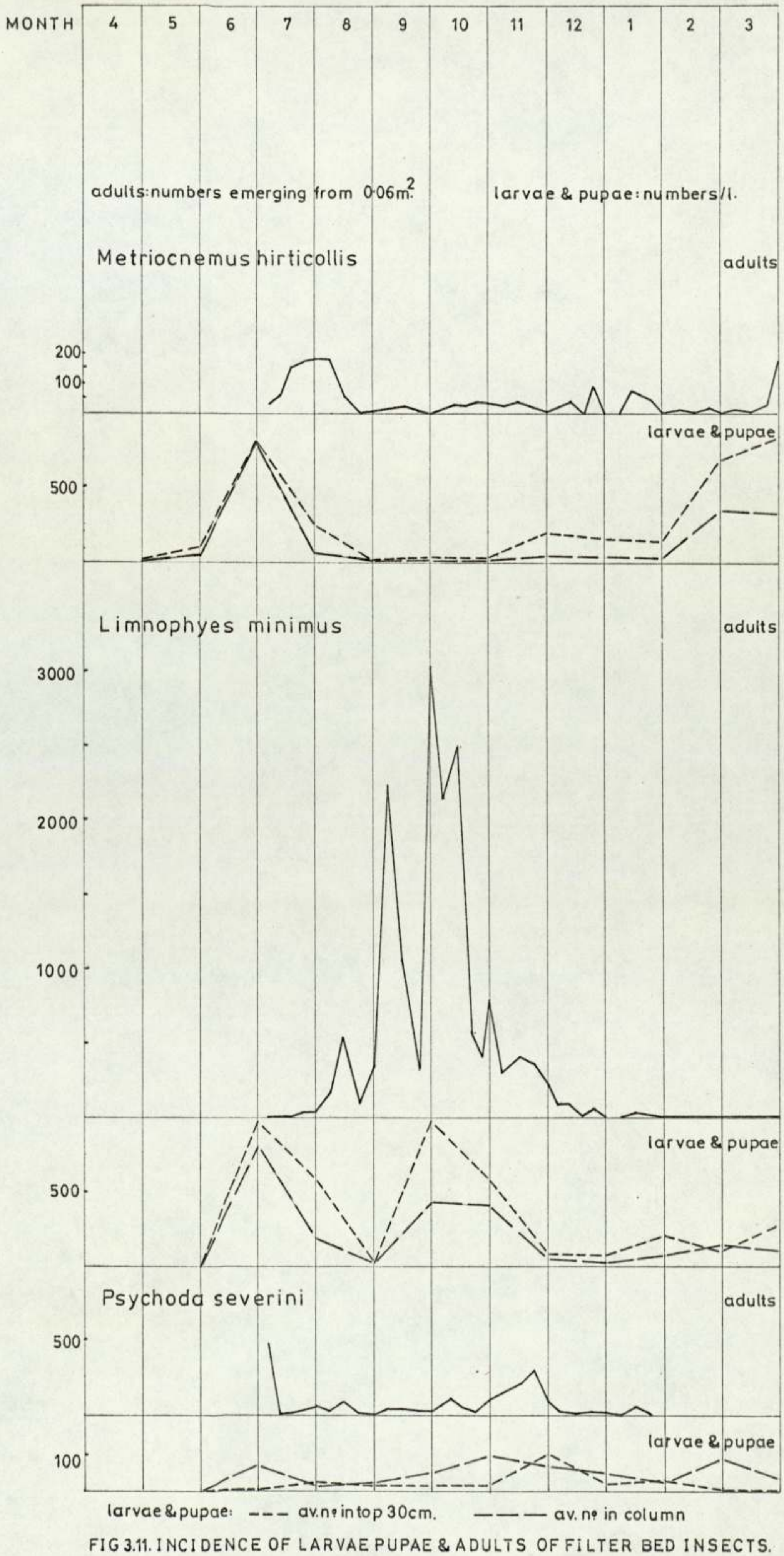


FIG 3.11. INCIDENCE OF LARVAE PUPAE & ADULTS OF FILTER BED INSECTS.

GOSPEL END S.T.W. 1969 - 1970.

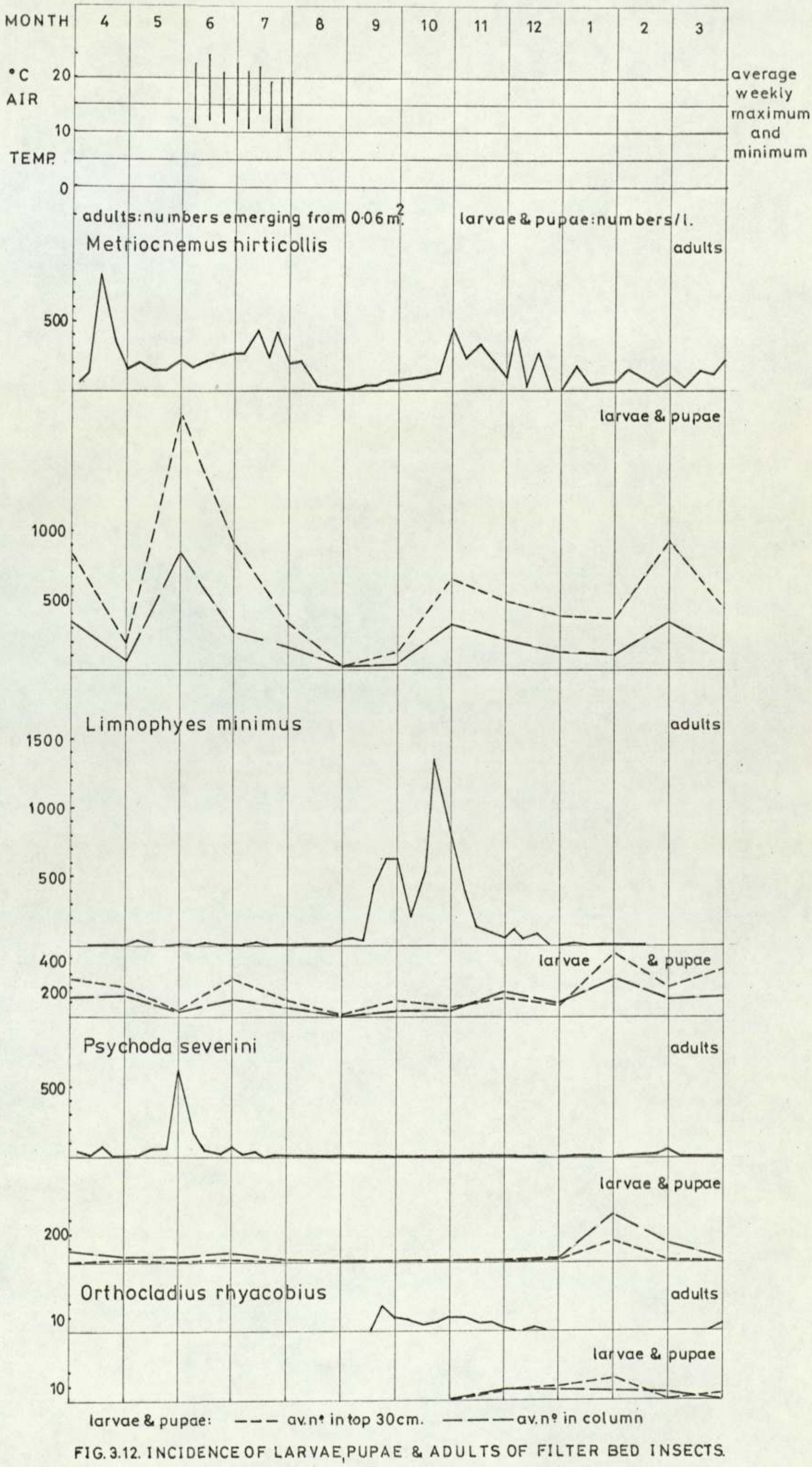


FIG. 3.12. INCIDENCE OF LARVAE, PUPAE & ADULTS OF FILTER BED INSECTS.

GOSPEL END S.T.W. 1970 - 1971.

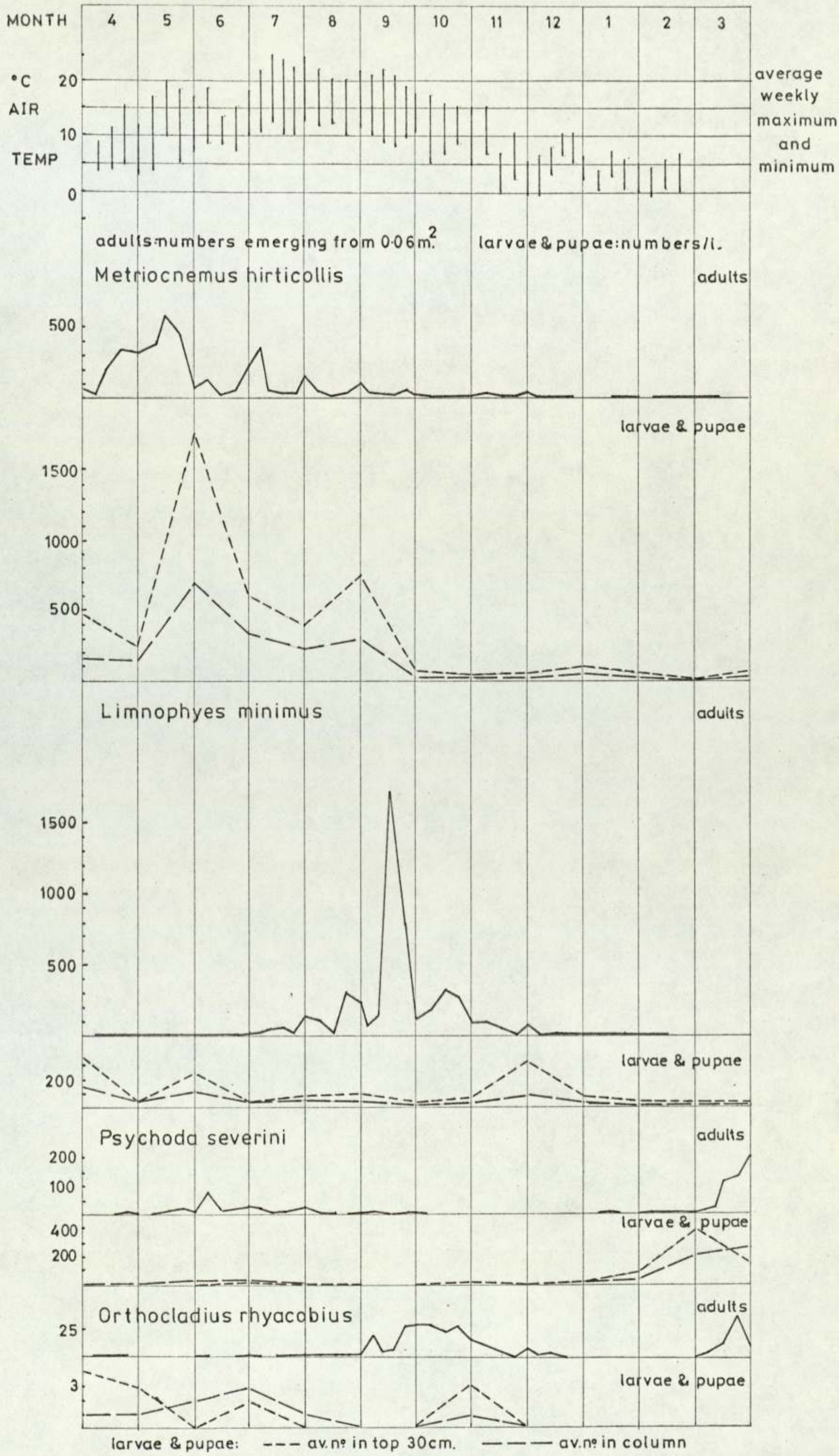


FIG. 3.13. INCIDENCE OF LARVAE, PUPAE & ADULTS OF FILTER BED INSECTS.

GOSPEL END S.T.W. 1971-1972.

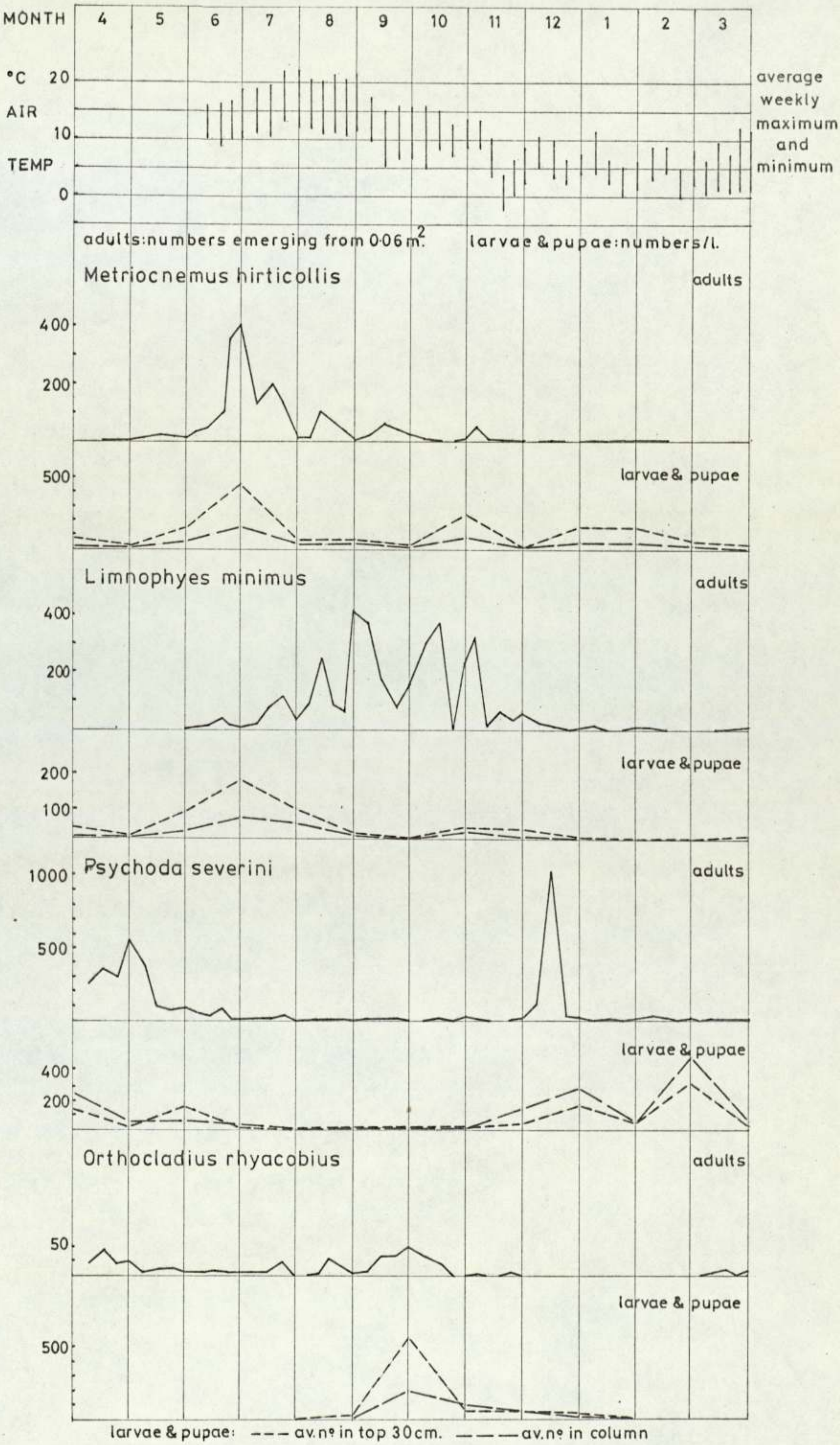


FIG. 3.14. INCIDENCE OF LARVAE, PUPAE & ADULTS OF FILTER BED INSECTS.

GOSPEL END S.T.W. 1972-1973.

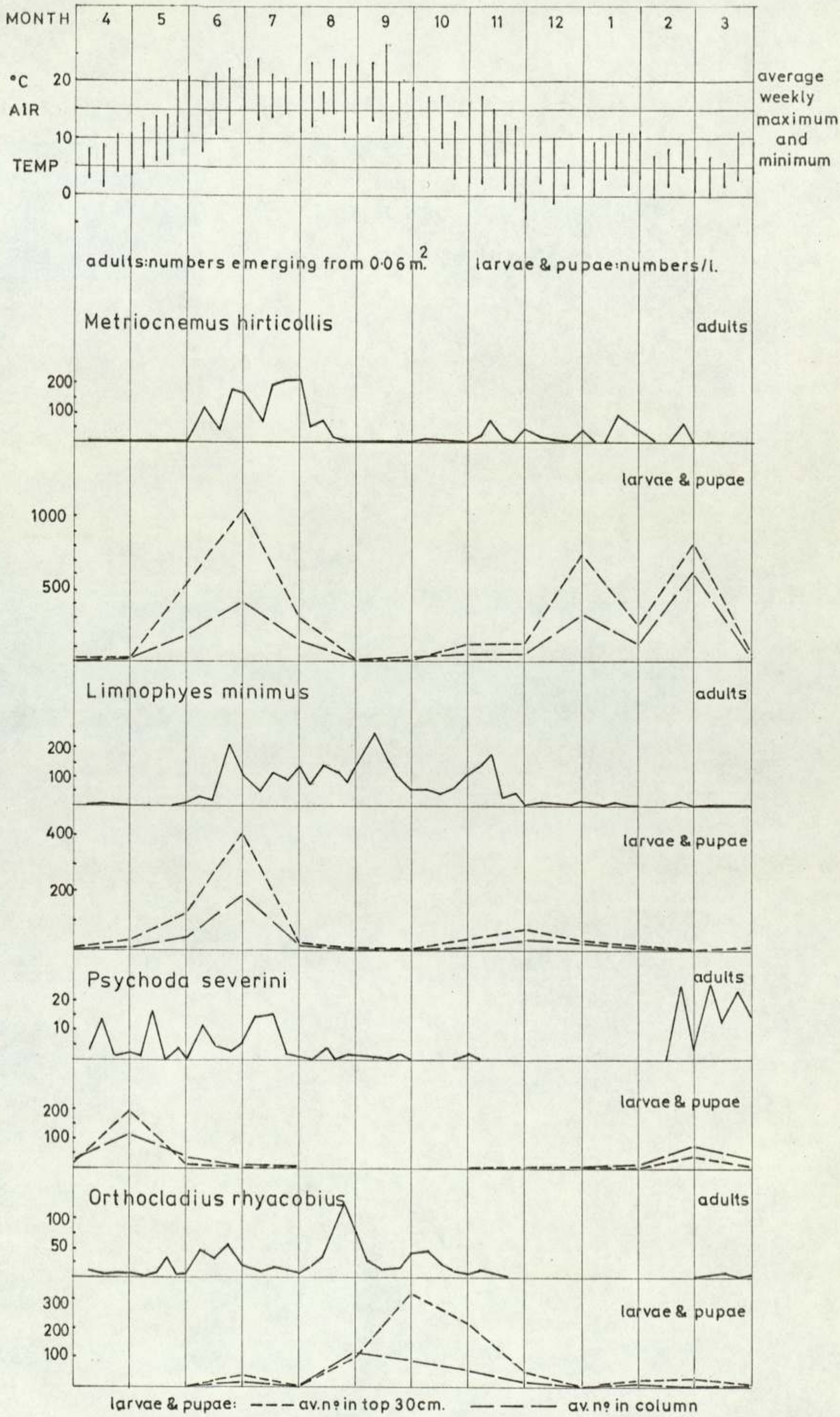


FIG.3.15. INCIDENCE OF LARVAE,PUPAE & ADULTS OF FILTER BED INSECTS. GOSPEL END S.T.W. 1973-1974.

June 1972 (Fig. 3.9.) and June 1973 (Fig. 3.10.). The greatest mean number found in the column was 845/1. of media in June 1969 and 978/1. of media in the upper 30 cm. in the same month (Fig. 3.6.). Largest numbers were found in the upper part of the filter.

After the initial eighteen months of colonization and maturation, Psychoda larvae and pupae were most abundant in the colder months of each year. A period of abundance usually lasted one or two months at the beginning of the year (Figs. 3.6. - 3.10.). This period extended from November to February on one occasion, 1972-1973 (Fig. 3.9.). The highest mean number of larvae and pupae/1. of media was 492 in the column and 320 in the upper 30 cm. in February 1973 (Fig. 3.14.). Thus, Psychoda was never found in as large numbers as Metriocnemus or Limnophyes; also Psychoda was rarely found in appreciable numbers in the uppermost part of the filter, except for February 1972 (Figs. 3.8. and 3.13.).

The distribution and abundance of Orthocladius rhyacobius larvae was sporadic until the last year of the study. Even then, it was common only between August and November (Fig. 3.10.). It was not found until November 1970 and often was absent from samples altogether (November 1971 to July 1972, October 1972 to May 1973). Like the other chironomids, it occurred mostly in the upper layers of the filter.

Enchytraeid worms, Lumbricillus (rivalis?) colonized the filter in July 1969, and were found every month after this. They were found most frequently during the first part of the calendar year (Figs. 3.6. - 3.10.). They occurred most abundantly in the upper layers of the filter and often in comparatively large numbers, e.g. mean of column 1450/1. of media in May 1972 and 981/1. in February 1973.

Lumbricid worms, *Eisenia* sp. and *Lumbricus rubellus*, did not occur in even moderate numbers until the middle of 1971 (Fig. 3.8.). Although they were found throughout the depth of the filter, they tended to be more common in the middle and lower parts. They were particularly common during the period May 1972 to July 1973 (Figs.3.9. and 3.10.).

Collembolans, *Hypogastrura* sp. were first found in August 1969 and increased in numbers until December 1969, when a mean of 443/1. in the column was found. After this they were found in varying numbers, but rarely in the August to October period. They gradually became less frequently found and none were found after March 1972. They rarely occurred in the uppermost layers and achieved their greatest abundance in the middle and lower layers.

Naid worms were rarely found during the first 21 months, but gradually became increasingly common during the investigation. There was no obvious re-occurring month of abundance, but none ~~were~~ was found in September of each year. The highest mean for the column was 151/1. of media in July 1973.

Catches of emerging insects were made for a 24 hour period each week, using one trap. Every year there were peaks of emergence, of varying intensity, of *Metriocnemus* *hirticollis* during July. Sometimes these peaks started earlier, in June in 1972 and 1973 (Figs. 3.14. and 3.15.) or sometimes extended into August, as in 1969 (Fig.3.11.). Additional peaks occurred at other times in some years, e.g. April and October to December 1970 (Fig.3.12.) and April to May 1971 (Fig. 3.13.). Major emergences of *Limnophyes minimus* occurred sometime during the period August to October each year. During the first year, particularly large emergences occurred (Fig. 3.11.), just over 3,000 being caught in the last week of September 1969. *Psychoda severini* showed considerable variation in the numbers of adults emerging and in the times of emergence during the five years of trapping. Adults of *Orthocladius rhyacobius* were not found until September 1970, and rarely formed the major percentage of the total emergence of all species in any one week. Occasionally other species, mainly Staphylimid beetles and Muscid flies, were found on the trap plates, but were very few in number.

Are you sure.

Tables 3.2. to 3.7. show the monthly averages of results of chemical analysis before and during the study period. Analysis of samples of settled sewage and final effluent was carried out once or twice a week on 8 hour composite samples, though these were not related to flow. The BOD of the final effluent rarely exceeded the Severn River Authority limit of 20 mg./l. and the effluent was usually well-nitrified. The BOD of the settled sewage varied considerably, partly because recirculated effluent was introduced before the primary sedimentation tanks sometimes, and at other times after the sedimentation

Month	Sett. Sew.		Final			
	B.O.D.	NH_3	B.O.D.	NH_3	$NO_2 + NO_3$	Zinc
1967						
Sept.	30	-	13	-	-	0.05
Oct.	135	-	21	-	21	-
Nov.	260	-	22	-	15	-
Dec.	135	-	31	-	14	-
1968						
June	-	-	-	-	35	-
July	-	-	-	-	24	-
Aug.	-	-	-	-	37	-
Sept.	-	-	-	-	-	-
Oct.	85	-	18	-	16	-
Nov.	-	-	-	-	15	-
Dec.	-	-	-	-	16	-
1969						
Jan.	62	24	15	7	14	-
Feb.	70	23	19	4	14	-
Mar.	56	20	20	6	3	-

Table 3.2. Monthly Means of Results of Chemical Analysis (8 hr. Composite) Gospel End S.T.W.

all figures in mg/l.

Month	Sett. Sew.		Final				
	B.O.D.	NH_3	B.O.D.	NH_3	$NO_2 + NO_3$	Total Metals	Zinc
1969/70							
Apr.	-	26	-	27	7	-	-
May	40	7	15	2	13	-	-
June	54	6	10	0.9	31	0.38	0.23
July	98	24	6	1	21	0.4	0.24
Aug.	39	8	8	0.5	11	0.26	0.09
Sept.	64	13	9	0.8	9	0.33	0.11
Oct.	109	25	10	1	20	0.5	0.27
Nov.	90	20	14	2	17	0.31	0.10
Dec.	94	21	11	3	21	0.21	0.09
Jan.	80	20	8	2	15	0.44	0.20
Feb.	71	19	12	1	15	0.34	0.17
Mar.	97	18	23	3	15	0.04	0.04

Table 3.3. Monthly Means of Results of Chemical Analysis (8 hr. Composite) Gospel End S.T.W.

all figures in mg/l.

Month	Sett. Sew.		Final				
	B.O.D.	NH_3	B.O.D.	NH_3	$NO_2 + NO_3$	Total Metals	Zinc
1970/71							
Apr.	100	17	12	3	18	0.14	0.14
May	80	19	15	1	14	0.15	Nil
June	212	38	10	4	27	0.14	0.04
July	128	24	13	1	29	0.06	0.06
Aug.	68	21	10	2	19	0.16	0.06
Sept.	118	24	13	1	24	Nil	Nil
Oct.	135	29	15	1	22	0.20	0.07
Nov.	79	25	8	2	17	0.16	0.11
Dec.	107	29	11	2	21	0.90	0.43
Jan.	81	23	12	1	17	0.49	0.22
Feb.	87	20	15	2	16	0.84	0.48
Mar.	71	22	11	1	16	0.54	0.24

Table 3.4. Monthly of Results of Chemical Analysis (8 hr. Composites) Gospel End S.T.W.

all figures in mg/l.

Month	Sett. Sew.		Final				
	BOD	NH_3	BOD	NH_3	$NO_2 + NO_3$	Total Metals	Zinc
1971/72							
Apr.	88	22	7	2	13	0.55	0.31
May	100	25	14	1	14	0.49	0.30
June	67	22	12	2	13	0.35	0.10
July	73	17	14	2	22	0.46	0.18
Aug.	29	11	13	1	22	0.36	0.16
Sept.	47	10	23	2	20	0.30	0.12
Oct.	70	20	23	1	27	0.37	0.13
Nov.	198	37	12	4	25	0.41	0.11
Dec.	212	45	6	3	24	0.35	0.09
Jan.	134	34	12	2	18	1.4	0.14
Feb.	175	34	14	2	24	1.16	0.68
Mar.	163	30	16	2	27	0.50	0.18

Table 3.5. Monthly Means of Results of Chemical Analysis (8 hr. Composites) Gospel End S.T.W.

all figures in mg/l.

Month	Sett. Sew.		Final				
	BOD	NH_3	BOD	NH_3	$NO_2 + NO_3$	Total Metals	Zinc
1972/73							
Apr.	160	-	13	0.9	29	1.38	0.90
May	150	-	13	0.9	29	0.56	0.20
June	163	-	8	1.0	31	0.69	0.24
July	234	-	11	1.8	33	0.62	0.21
Aug.	98	-	8	2.9	24	0.85	0.16
Sept.	117	-	7	1.7	23	0.59	0.16
Oct.	112	-	7	2.6	22	0.45	0.10
Nov.	116	-	14	2.3	18	0.59	0.16
Dec.	97	-	13	2.5	15	0.70	0.15
Jan.	93	-	19	1.7	18	0.55	0.17
Feb.	72	-	11	1.6	18	0.93	0.20
Mar.	76	-	17	2.2	17	0.90	0.30

Table 3.6. Montnly Means of Results of Chemical Analysis (8 hr. Composites) Gospel End S.T.W.

all figures in mg/l.

Month	Sett. Sew.		Final Effluent				
	B.O.D.	NH_3	B.O.D.	NH_3	$NO_2 + NO_3$	Total Metals	Zinc
1973/74							
April	69	-	13	2	19	0.62	0.11
May	56	-	13	2	14	0.84	0.20
June	32	-	14	2	23	0.74	0.12
July	30	-	10	3	14	0.86	0.40
Aug.	42	-	7	2	11	1.2	0.12
Sept.	55	-	8	1	9	1.4	0.25
Oct.	51	-	4	1	14	-	-
Nov.	76	-	5	3	16	0.75	0.32
Dec.	69	-	9	1	20	0.93	0.56
Jan.	37	-	8	1	14	0.56	0.26
Feb.	53	-	11	1	16	0.58	0.15
Mar.	66	-	22	1	14	0.84	0.19

Table 3.7. Monthly Means of Results of Chemical Analysis (8 hr. Composite) Gospel End S.T.W.

all figures in mg/l.

tanks. According to Bolton and Klein (1971), the Gospel End settled sewage would be classified as weak or even very weak.

3.2.2. Roundhill S.T.W.

It had been intended to sample in each month one filter receiving primary feed and one receiving secondary feed; however, because of major and minor breakdowns this sampling sequence was not always possible. It was achieved in 16 out of 22 months.

During the first two months spot samples of feed to the two sets of filters were taken, in order to ascertain the types of microorganisms being introduced in the sewage. The microorganisms most frequently found in the primary feed included nematodes, Vorticella microstoma, Opercularia coarctata, Euplotes sp. and to a lesser extent Colpidium sp., Hemiophrys sp., and Stylonychia sp. Those occurring most abundantly in the secondary feed were nematodes, Vorticella microstoma, Euplotes sp., Opercularia coarctata and Colpidium sp.

Examination of the first set of samples from each filter revealed the following microfauna common to both filters (Table 3.8.); nematodes, Opercularia coarctata, Vorticella microstoma, Amoeba proteus, Litonotus sp., Colpidium sp., Podophrya sp., and Paramecium sp. Euplotes sp. and Stylonychia sp. were found only in filter 3, the first to receive sewage, whereas Amoeba radiosa and tardigrades were confined to filter 2. During the following two months, Trachelophyllum sp., Carchesium polypinum, Aspidisca costata, Rotaria sp., Vorticella convallaria and

Table 3.8.

Microinvertebrates found in filters 2 and 3 at Roundhill S.T.W.

Microorganism	First Occurrence	
	Filter 2*	Filter 3**
Nematoda spp.	2/72	2/72
Opercularia coarctata	2/72	2/72
Vorticella microstoma	2/72	2/72
Amoeba proteus	2/72	2/72
Litonotus sp.	2/72	2/72
Colpidium sp.	2/72	2/72
Amoeba radiosa	2/72	4/72
Podophrya sp.	2/72	2/72
Paramecium sp.	2/72	2/72
Tardigrade sp.	2/72	11/73
Carchesium polypinum	3/72	6/72
Stylonychia sp.	3/72	2/72
Aspidisca costata	3/72	6/72
Trachelophyllum pusillum	3/72	3/72
Euplotes sp.	3/72	2/72
Rotaria sp.	3/72	3/72
Vorticella convallaria	4/72	4/72
Opercularia minima	4/72	3/72
Tokophyra sp.	7/72	-
Arcella sp.	7/72	8/72
Flagellate spp.	7/72	6/72
Amphileptus sp.	9/72	9/72
Aelosoma hemprichii	9/72	-
Chilodonella sp.	11/72	10/72

* Filter started 17.1.72.

**Filter started 3.1.72.

Opercularia minima appeared. All the species, which were found during the two year study, had appeared by November 1972, some ten months after the first flow to the works.

The most abundantly occurring microorganisms over the two year period were Nematoda spp., Opercularia coarctata and Vorticella convallaria (Figs. 3.16. to 3.19.). Other species which occurred in appreciable numbers, but for a restricted period, were Amoeba proteus in March 1972 in filter 2 and in April 1972 in filter 3, rotifers (Rotaria sp.) in October 1972 in filter 3 and in November and December in filter 2, and Opercularia minima in July 1973 in filter 3. Despite their frequency in the filter feed examined during the first few months, Euplotes sp., Vorticella microstoma and Colpidium sp. never became established in the filters.

Nematode species were found distributed fairly evenly throughout the filters and usually in substantial numbers (Figs. 3.16 - 3.19.). The highest mean for filter 2 was 219,000/g. of dried film in May 1973 and for filter 3, 186,000/g. in February 1973. The peaks of abundance of Opercularia coarctata and Vorticella convallaria seemed to be inversely correlated during 1972, with O. coarctata somewhat more abundant. (Figs. 3.16. and 3.17.). In 1973, Opercularia coarctata was found in increasingly large numbers, especially after July (Figs. 3.18. and 3.19.). Until the beginning of the second year, O. coarctata was found fairly evenly throughout the filters, but in the second year there was a tendency towards greater abundance in the

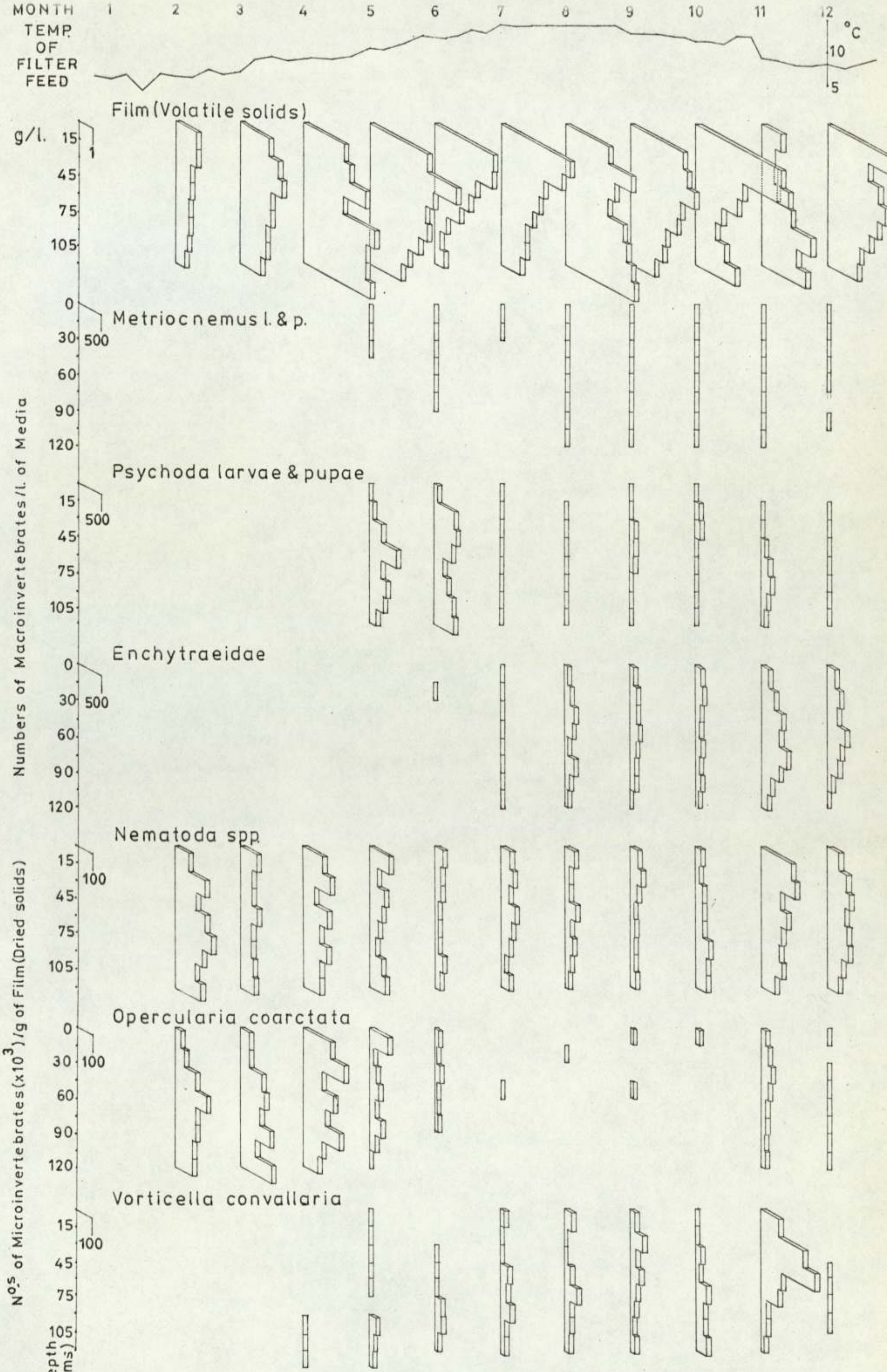


FIG.3.16. VERTICAL DISTRIBUTION OF FILM AND FAUNA BED 2. ROUNDHILL S.T.W. 1972.

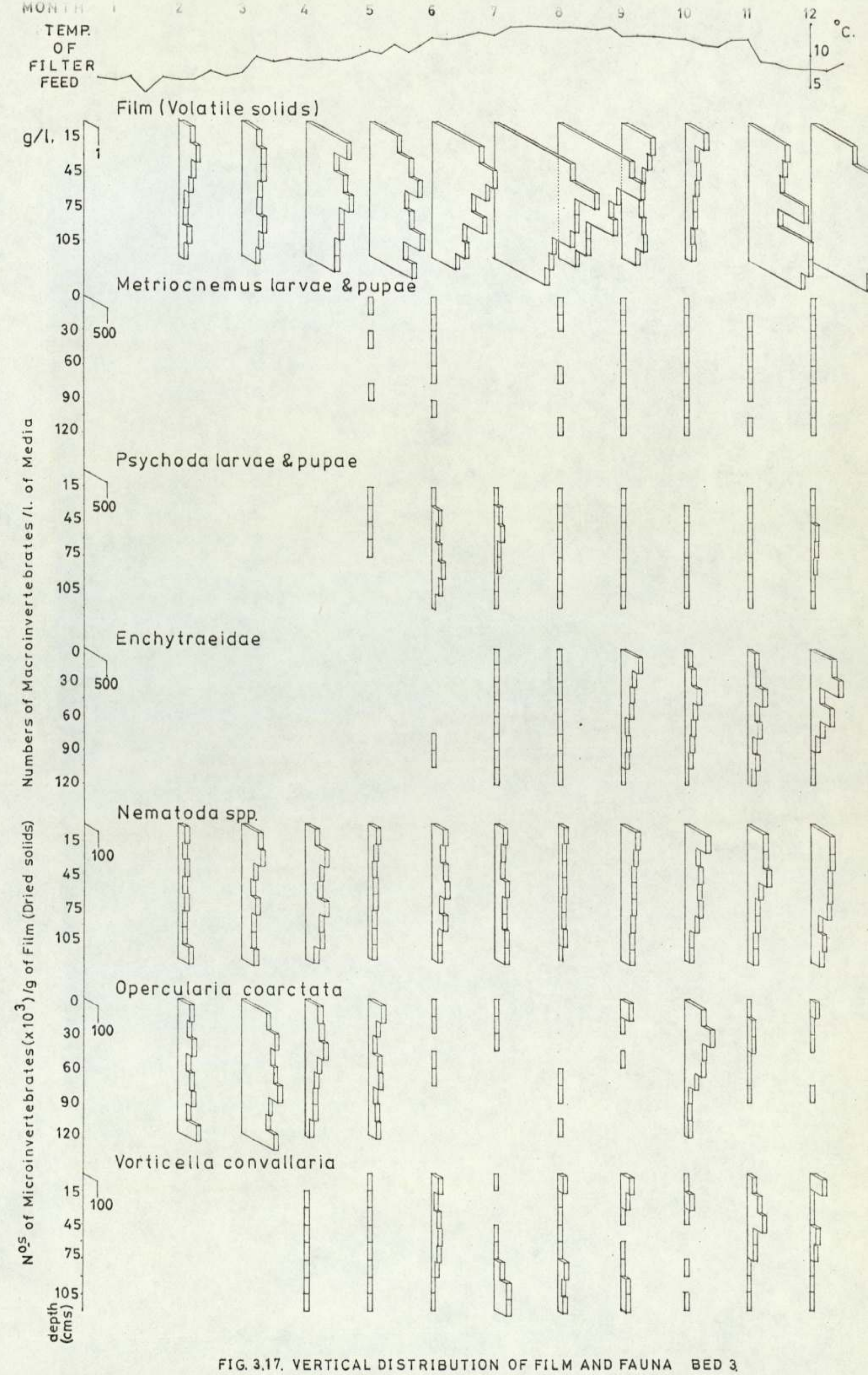


FIG. 3.17. VERTICAL DISTRIBUTION OF FILM AND FAUNA BED 3 ROUNDHILL S.T.W. 1972.

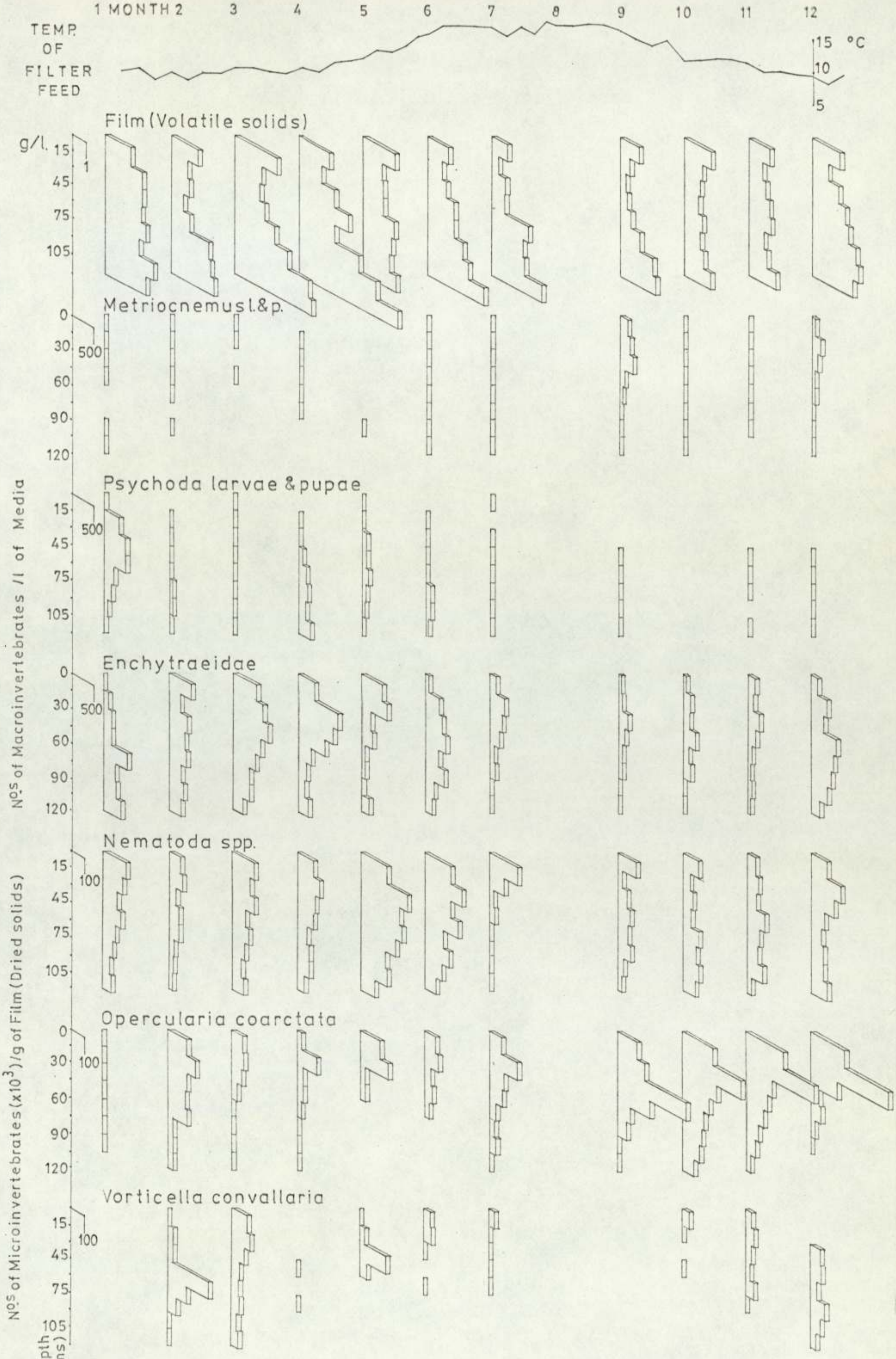


FIG.3.18. VERTICAL DISTRIBUTION OF FILM AND FAUNA BED 2. ROUNDHILL ST.W. 1973.

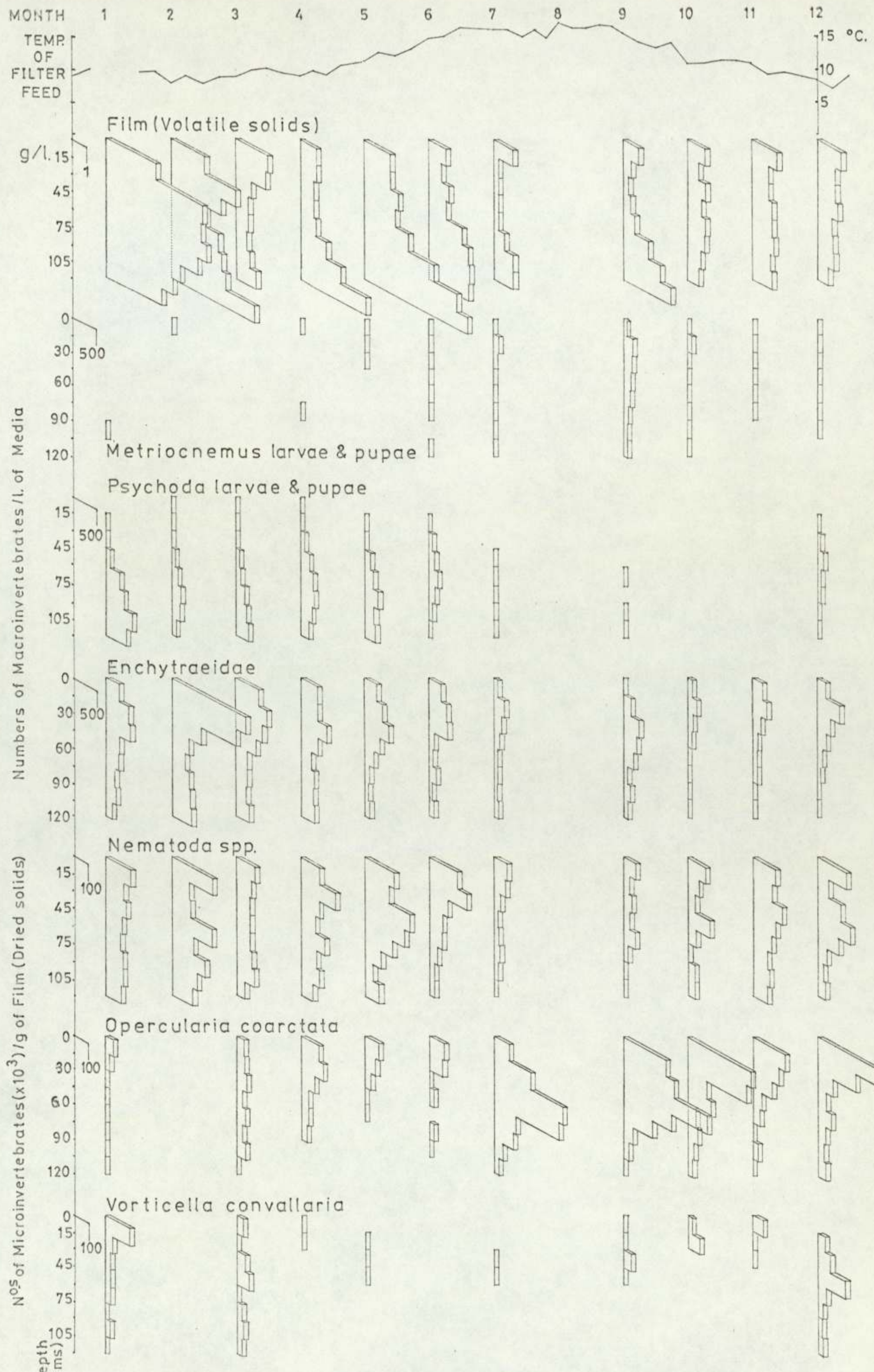


FIG.3.19. VERTICAL DISTRIBUTION OF FILM AND FAUNA BED 3.
ROUNDHILL S.T.W. 1973.

upper parts of the filters (Figs. 3.18 and 3.19.). The greatest numbers found were 231,000/g. in filter 3 in September 1973 (Fig. 3.19.) and 192,000 in filter 2 (Fig. 3.18.). V. convallaria, on the other hand, was found in decreasing numbers over the two years, and when common was more frequently found in the middle parts of the filters (Figs. 3.16. to 3.19.). The highest mean for filter 2 was 141,000/g. in November 1972 (Fig. 3.16.), and in filter 3, 55,000/g. in December 1973 (Fig. 3.19.).

There was no correlation between the type of feed and the comparative numbers of each of the species in the two filters. However, nematodes seemed to be little affected when breakdowns occurred and feed to a filter was stopped, whereas O. coarctata, in filter 3 in February 1973 and V. convallaria, in filter 2 in January 1973, and in filter 3 in February 1973, were adversely affected when flow stopped for a long period (Figs. 3.18 and 3.19).

No macroinvertebrates were encountered until May 1972, when a few Metriocnemus larvae were found in both filters and a few Psychoda larvae in filter 3, and fairly substantial numbers in filter 2. (Figs. 3.16 and 3.17). Metriocnemus larvae and pupae were not found in large numbers in either filter throughout the investigation, the highest mean numbers for the column were 107/l. in filter 2 (Fig. 3.18) and 95/l. in filter 3 (Fig. 3.19) in September 1973. They tended to be more common in the upper parts of the filters (Figs. 3.20 and 3.21.).

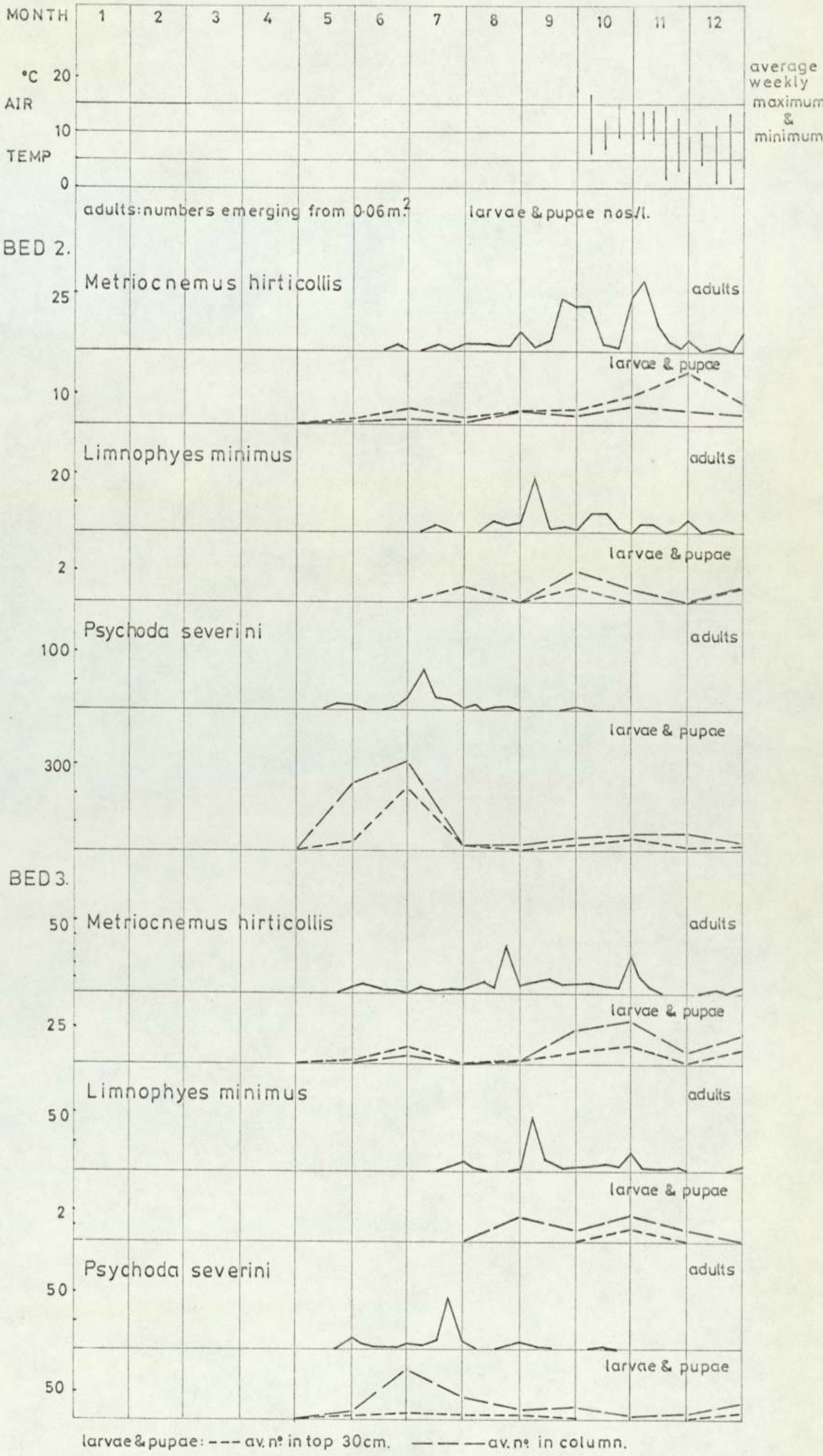


FIG. 3.20. INCIDENCE OF LARVAE, PUPAE & ADULTS OF FILTER BED INSECTS.

ROUNHILL S.T.W. 1972.

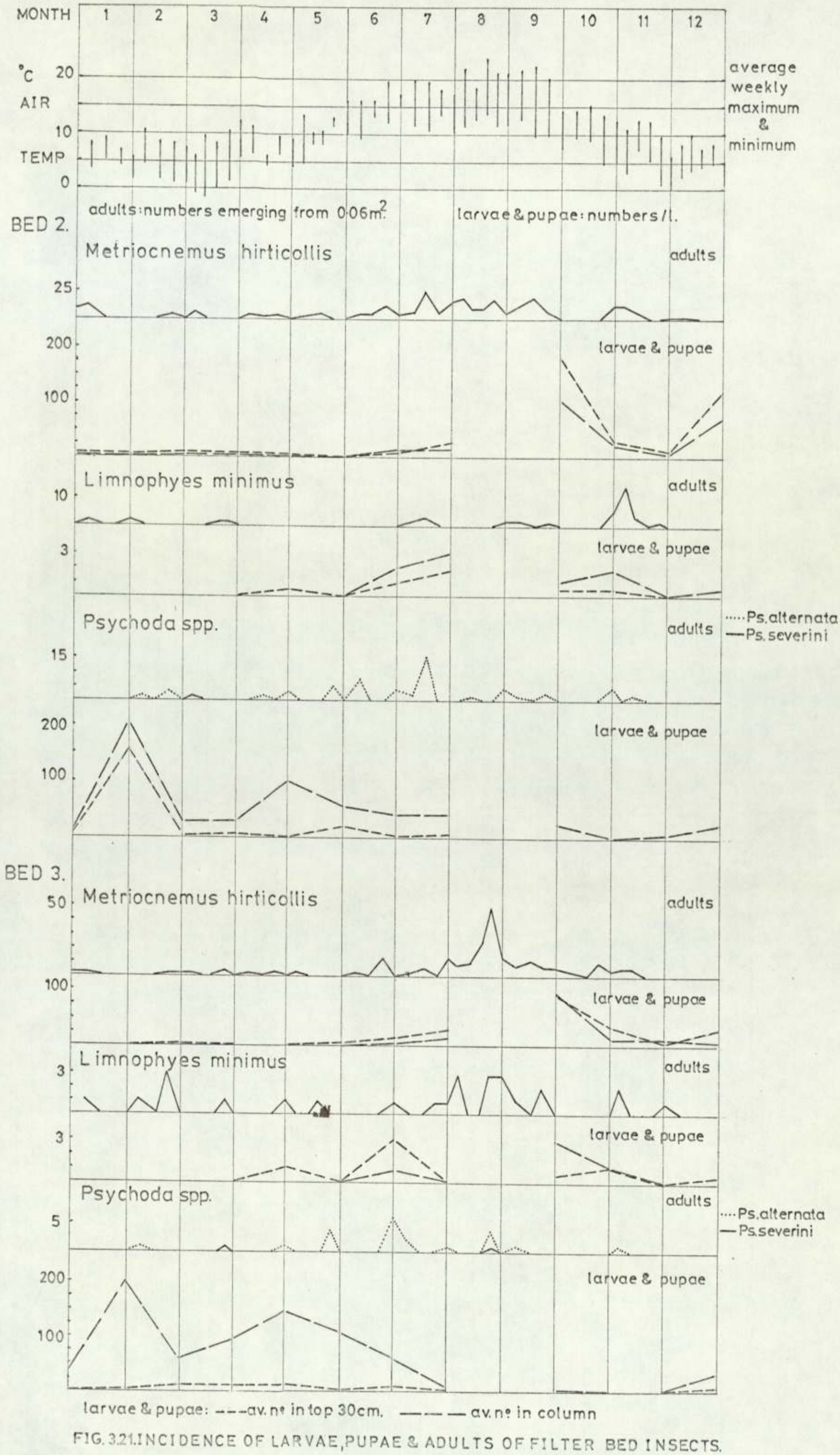


FIG. 3.21. INCIDENCE OF LARVAE, PUPAE & ADULTS OF FILTER BED INSECTS.

ROUNDHILL S.T.W. 1973.

Psychoda larvae and pupae were more abundantly found in the middle and lower parts of the filter (Figs. 3.16 to 3.19, and 3.20 and 3.21.), and occurred in greater numbers. The highest mean numbers for the columns was 312/l. in filter 2 in June 1972 (Fig. 3.16) and 199/l. in filter 3 in January 1973 (Fig. 3.19). Limnophyes larvae and pupae were found in both filters, but never in large numbers.

Enchytraeid worms, Lumbricillus (rivalis?), however, which were first found in June 1972, increased considerably and once established, became the dominant macroinvertebrate found over the two years. Although distributed throughout the depths of the filters, the worms were more abundant in the upper and middle parts (Figs. 3.16. to 3.19.). The highest mean numbers for the columns occurred in March 1973 in filter 2 (Fig. 3.18) when 485/l. were found and in February 1973 (Fig. 3.19) in filter 3 when 654/l. were found.

Naididae worms first appeared in September 1972, never occurred in large numbers, and tended to be confined to the middle and lower parts of the filters. Lumbricid worms were not found at all. Other groups occurring included larvae and pupae of Ceratopogonidae (Diptera), some unidentified chironomid larvae and occasional Dipteran (Muscidae) larvae.

Figures 3.20 and 3.21. show the incidence of adult emergence compared with the numbers of larvae and pupae found in the top 30 cm. and in the whole column of the sampling shafts. Catches were made, using one trap on each filter, for a 24 hour period each week.

Month	Crude Sewage		Final Effluent				
	B.O.D.	NH_3	B.O.D.	NH_3	$NO_2 + NO_3$	Total Metals	Zinc
1971							
Jan.	263	33	137	36	5	0.64	0.32
Feb.	300	35	81	29	4	0.89	0.35
Mar.	630	33	60	21	3	0.72	0.27
Apr.	-	73	-	40	2	0.48	0.23
May	235	43	62	27	4	2.81	2.40
June	150	23	50	16	3	0.66	0.20
July	489	34	53	24	5	0.76	0.30
Aug.	187	31	38	20	4	0.54	0.16
Sept.	460	53	58	22	6	0.56	0.21
Oct.	428	29	37	25	2	0.47	0.16
Nov.	440	46	50	22	2	0.94	0.42
Dec.	283	38	188	31	1	1.15	0.55
1972							
Jan.	103	14	202	21	4	1.5	0.38

Table 3.9. Monthly Means of Results of Chemical Analysis.
Roundhill Farm

all figures in mg/1.

MONTH	SETT SEW			PRIM.EFFL.		SEC.FEED		SEC.EFFL.		FINAL				
1972	BOD	N/8PV	NH_3	BOD	NH_3	BOD	NH_3	BOD	NH_3	BOD	NH_3	NO_2 + NO_3	TOTAL METALS	ZINC
JAN														
FEB										37	31	2	0.75	0.36
MAR	171									51	12	5	-	-
APR	229	80	27	82	19	67	19	36	13	44	10	12	-	-
MAY	268	61	27	117	23	91	16	61	11	48	10	7	0.77	0.27
JUNE	191	63	27	67	16	46	16	44	8	37	7	10	0.56	0.24
JULY	180	57	30	61	19	50	14	50	8	30	5	10	-	-
AUG	161	59	33	44	19	28	11	26	7	17	6	17	-	-
SEPT	153	56	34	66	19	39	10	46	4	20	3	30	0.93	0.46
OCT	181	55	34	78	18	44	15	52	8	25	7	27	-	-
NOV	197	54	30	45	23	29	11	28	5	12	4	37	-	-
DEC	147	40	27	40	19	34	11	27	6	20	4	24	0.72	0.17

all figures in mg/l

Table 3.10. Monthly Means of Results of Chemical Analysis of 24 hr Composite Samples. Roundhill S.T.W.

MONTH	SETT. SEW			PRIM.EFFL.		SEC. FEED		SEC. EFFL		FINAL				
1973	BOD	N/8PV	NH_3	BOD	NH_3	BOD	NH_3	BOD	NH_3	BOD	NH_3	NO_2+ NO_3	TOTAL METALS	ZINC
JAN	200	75	30	-	15	-	15	-	4	39	4	24	-	-
FEB	194	57	27	75	22	50	16	44	11	26	10	17	0.76	0.23
MAR	140	55	25	48	19	31	12	31	9	18	11	17	0.89	0.28
APR	149	69	29	48	16	32	14	38	8	17	5	28	-	-
MAY	148	64	31	56	14	30	12	33	5	18	4	26	-	-
JUNE	136	38	27	55	12	30	7	40	1	23	1	32	-	-
JULY	146	48	32	73	12	44	4	50	1	23	1	30	-	-
AUG	159									15	1	-	0.93	0.16
SEPT	170									14	1	-	1.00	0.35
OCT	151									16	2	23	-	-
NOV	187									24	6	19	1.18	0.38
DEC	152									15	9	15	0.91	0.43

all figures in mg/l

Table 3.11 Monthly Means of Results of Chemical Analysis of 24 hr. Composite Samples. Roundhill S.T.W.

During the first year the numbers of adults emerging from the filters were few, the greatest incidence being for Psychoda severini in July 1972. Metriocnemus hirticollis showed greatest emergence during the August to November period. In September, Limnophyes minimus showed an increased emergence, but was found decreasingly thereafter. During the second year, 1973, only Metriocnemus emerged in even moderate numbers. Psychoda alternata had replaced P. severini to a large extent, but did not occur in large numbers.

Prior to the building of the Roundhill S.T.W., sewage had been treated by irrigation on farmland. Table 3.9. shows the monthly averages of chemical analysis during 1971. The efficiency of this type of treatment was very poor, especially in the colder months, when very high figures for BOD and ammonia were found. Tables 3.10. and 3.11. show the results of chemical analysis during the first two years of operation of the Roundhill S.T.W. Although initially above the limits imposed by the River Authority, 20 mg./l., by the second year the BOD in the final effluent was often well within the limits and fairly good nitrification was being achieved. The strength of settled sewage would be classified by Bolton and Klein (1971) as average or slightly less than average, though the inclusion of industrial wastes might have rendered it more difficult than average to treat.

3.3. Discussion

3.3.1. Comparison of colonization of filters at the two works

The conditions under which colonization took place in the filters at the two works differed in the following respects. The filter at Gospel End received, from the first, a feed which contained microorganisms and possibly macrofauna from filters which were already functioning, whereas the filters at Roundhill received settled sewage, containing only microorganisms derived from the drainage area. Secondly, the feed at Gospel End was diluted by recirculated effluent, whereas at Roundhill the feed to filter 3, for the first four weeks, received no dilution, but that to filter 2 was secondary feed (Figs. 2.4. and 2.5.). In addition, the Roundhill settled sewage was stronger and a proportion of it was industrial in origin.

Tables 3.1, 3.8 and 3.12. (pages 100, 130 and 145) show the microorganisms found in filters at the two works and the month of their first appearance in samples of film. Despite the differences in conditions, it can be seen, that during the first six months a similar number of species of microorganisms had colonized the filters, 22 species at Gospel End and 20 at Roundhill. However, there was a difference in the microfauna composition of the first few months. The filter at Gospel End was characterised by the sudden increase and then decrease of a number of species, notably Stylonychia sp., Colpoda sp., Paramecium sp. and Rotaria sp., whereas in both filters at Roundhill two of the taxa, which were to comprise much of the microfauna in the subsequent two years, namely Nematoda spp. and Opercularia coarctata were found in the first month as dominant species.

Table 3.12.

Comparison of microfauna found in filters at Gospel End and Roundhill S.T.W.

Microorganisms found at both works	Microorganisms found only at Gospel End	Microorganisms found only at Roundhill
Nematoda spp.	Colpoda sp.	Flagellate sp.
Vorticella convallaria	Ileonema sp.	
V. microstoma	Encentrum sp.	
Opercularia coarctata	Stentor polymorphus	
O. minima	Spirostomum sp.	
Carchesium polypinum	Acineta sp.	
Amoeba proteus	Hemiophrys fusidens	
A. radiosa	H. pleurosigma	
Litonotus sp.		
Aspidisca costata		
Euplotes		
Stylonychia sp.		
Trachelophyllum sp.		
Paramecium spp.		
Amphileptus sp.		
Colpidium sp.		
Rotaria sp.		
Chilodonella sp.		
Aelosoma hemprichii		
Arcella sp.		
Podophrya sp.		
Tokophrya sp.		
Tardigrade sp.		

Presumably they were the least susceptible to the type of feed at Roundhill. Nematoda spp. appeared at Gospel End in the first month in fairly large numbers, but Opercularia coarctata and Vorticella convallaria, the other two common species during the investigation, did not appear in substantial numbers until four or five months had elapsed. It may be, that the weaker filter feed at Gospel End enabled a number of species to become established initially, but competition for a diminishing source of food (Fig. 3.1. June) led to the drastic decrease in some populations. Nematoda species survived this period and increased in numbers, when a greater supply of food became available in July, to become one of the dominant groups.

It would appear, therefore, that although the Gospel End filter received a 'seed' of microorganisms from an operating filter, which probably helped in the establishment of a microfauna in the study filter, in this instance the rate of colonization was no greater than that in the Roundhill filters, which did not receive such a 'seed'. Whether the fact that the future dominant species became established in the Roundhill filters from the first was fortuitous is not possible to determine.

The facts that the Gospel End filter received filter effluent from other filters, and was in close proximity to other filters, were certainly advantages in the early colonization of the filter by macroinvertebrates (Fig. 3.6.). Although few in number, Metriocnemus larvae were found in the first month, The months when the filter-beds started operating will also be important. The Roundhill filters were started in January compared with March for Gospel End. Thus care must be taken in comparing them.

whereas in the Roundhill filters no macroinvertebrates were found until four months had elapsed. Large populations of Metriocnemus and Limnophyes developed at Gospel End within three months of the start of operating (Fig. 3.6.). Psychoda larvae, Enchytraeidae and Lumbricidae all appeared within six months and increased their populations at different rates. At Roundhill, development and establishment of large macroinvertebrate populations was hampered by the considerable accumulation of film. Only enchytraeids proved even partially successful in the first two years, so that the community was far from mature at the end of the study. At Huddersfield, Reynoldson (1947) found that well within 14 days Enchytraeus albidus had attained similar proportions in a bag of scalded Phormidium placed in a filter as in the rest of the filter. Solbé et al. (1967) in their investigation of an experimental filter, receiving an 'average' (Bolton and Klein, 1971) BOD loading, studied the sequence of colonization and found that Psychoda severini was the first to colonize the filter, followed by collembolans, enchytraeids, Metriocnemus hygropetricus, Ps. alternata and finally, after 10 months, lumbricids. Here proximity to other filters also facilitated rapid colonization by adult insects. These findings, generally, agree with the pattern at Gospel End of insects being the first colonizers followed later by enchytraeid and lumbricid worms.

[illegible]s not see [illegible] point of [illegible]luding [illegible] this.

3.3.2. Changes in film and fauna

Comparisons have been made by a number of workers

(Barker, 1949; Hawkes, 1963) between the protozoa found in activated sludge systems with those found in percolating filters. It has been shown, that a stratification of species exists in filters, with those more typical of a less-efficient sludge being found in the upper parts of the filter and those lower down being associated with well-purified sludges. Holotrich protozoans, such as Paramecium, Colpoda, Colpidium and one peritrich Vorticella microstoma, are usually associated with inefficient sludge and peritrichs and hypotrichs with efficient sludge (Hawkes, 1963).

The results from both works show, that peritrichs were the most abundantly found protozoans in the established communities. Curds and Cockburn (1970), in a countrywide survey of 52 percolating filters, confirmed that peritrich ciliates were the most important group of protozoans in aerobic processes. Tomlinson and Snaddon (1966) in their study of microorganisms in rotating tubes found, that Vorticella was found most abundantly in the upper sections. This distribution was also found for Vorticella convallaria at Gospel End, but at Roundhill the middle zone seemed to support the largest populations of this species for most of the year. Opercularia, on the other hand, was rarely found by Tomlinson and Snaddon (1966) in the upper section. At Gospel End, Opercularia coarctata was rarely found near the surface, apart from August 1969 and 1970 (Figs. 3.1. and 3.2.) and April and May 1972 (Fig. 3.4.), whereas at Roundhill it was found throughout the filters, often showing its greatest concentrations at or near the surface (Figs. 3.18. and 3.19.).

Obviously a number of factors were interacting to determine the density and distribution of Opercularia coarctata, but one of the most important of these would appear to have been the activity of the grazing fauna, especially of the chironomids in the Gospel End filter, and to a lesser extent, Psychoda in the Roundhill filters. Barker (1946, 1949) showed, that the abundance of ciliates was inversely proportional to that of the grazing insect larvae. In the Gospel End filter, there was a distinct inverse correlation between the abundance of chironomid larvae and Opercularia coarctata. Figures 3.1. and 3.6. show, that when there were large populations of Metriocnemus and Limnophyes larvae and pupae in June, there were very few Opercularia, but in August, when most of the chrionomids had become adults, Opercularia was abundant, especially at the surface. The second peak of Limnophyes larvae and pupae in September and October coincided with a corresponding decline in Opercularia. A similar pattern emerges in the following year (Figs. 3.2. and 3.7.). In November 1970, there was an increase in Opercularia in the lower part of the column at the same time as only a small increase in Metriocnemus in the upper part. It would seem likely, that at this time Opercularia was confined to the lower part by the increasing activity of enchytraeid worms higher up the column. Also increased competition from Vorticella convallaria nearer the surface could have influenced the distribution of Opercularia.

In spring 1972 (Figs. 3.4. and 3.9.) Opercularia was again abundant when numbers of Metriocnemus and Limnophyes were low, but in the following winter, when numbers of the chironomids were still low, the density of Opercularia seemed to be more affected by the abundance of Psychoda and enchytraeids, especially over the period January to March 1973. Barker (1949), however, thought that Opercularia was adversely affected by low temperatures. In the summer of 1973, when numbers of Metriocnemus and Limnophyes were very low, Opercularia was also sparse probably because of the increased importance of Orthocladius rhyacobius, whose larvae were common in the upper layers between August and October. In fact, throughout the year the succession of peaks of different grazers probably had some influence in keeping numbers of Opercularia low. The density and vertical distribution of Vorticella convallaria was inversely correlated with that of Metriocnemus larvae and pupae over the period October 1973 to March 1974. In previous years, however, the monthly distribution of Vorticella seemed to be inversely correlated with that of Opercularia and although affected by the abundance of Metriocnemus the vorticellid populations were rarely decimated (except February 1970, Fig. 3.5.) in the same way as those of Opercularia, by the activities of the larvae.

Similar patterns emerged from the results of sampling in the Roundhill filters, despite the shorter duration of the investigation. The effect of

Metriocnemus here was minimal, but Psychoda was more important. The populations of Opercularia and Psychoda were inversely abundant for much of the period (Figs.3.16 to 3.19.). At the beginning of the filter operation, Opercularia was found throughout the filter in appreciable numbers, but in the second year they were much more abundant in the upper parts. This was probably due in part to the activities of Psychoda larvae or possibly to the greater accumulations of film in the lower sections during this time. Generally, Opercularia was more successful than the other common protozoan, Vorticella convallaria, and when abundant tended to restrict Vorticella to the lower layers.

Both at Gospel End and at Roundhill, Vorticella microstoma was of little significance, and tended to be restricted to the upper parts of the filters. This would agree with the observations of Hawkes (1963) that this species is associated with inferior sludges and thus its position in the upper layers, where the feed is stronger, would be expected. Barker (1949) indicated that Carchesium was favoured by conditions in the deeper zones of filters. At Gospel End, Carchesium polypinum was found sporadically and sometimes in large numbers. It tended to be most common in the upper to middle layers (Figs. 3.1. to 3.5.), but since the feed was rather weak organically, it is probable that this species was able to extend its range upwards.

Of the holotrichs only Paramecium was found in appreciable numbers at Roundhill and its distribution pattern agreed with the stratification theory stated above. At Gospel End, *Paramecium* sp., *Colpoda* sp. and *Colpidium* sp. were found and these too were more abundant in the upper half of the filter. Of the hypotrichs *Aspidisca costata* was more frequently found in the upper parts of the filters at both works, and *Stylonychia* sp., although not occurring often, was, when found, abundant in the uppermost layers especially. To explain this similar occurrence in filters receiving different types of feed is problematical, except to suggest that these species possibly have a wide range of tolerance. Although Curds and Cockburn (1970) mention that species of *Arcella* were commonly encountered, no indication was given of vertical distribution. It was found at Gospel End, that *Arcella* was almost entirely confined to the lower layers of the filter. This agrees with the findings of Cutler *et al*. (1932), who studied the vertical distribution of protozoan species in experimental filters.

The density of the protozoan fauna was found by Barker (1949) to be greatest in filters receiving a weak, domestic sewage and least in filters receiving a proportion of industrial waste in the sewage. Conversely, the filters receiving a stronger feed had less restriction of numbers of protozoan species, a feature characteristic of low purification, whilst the filters receiving a weak feed had the restricted microfauna of well-purified effluents. In the present studies there was little or no difference in the number of species found at various levels in any of the filters, but there were distinctly more individuals found in the upper layers than the lower at Gospel End, and in the second year at Roundhill, though during the first year there was a more even distribution of individuals through the Roundhill filters. There was a distinct difference in the numbers of species found, however, there usually being almost twice as many species at each level at Gospel End as at Roundhill, which was contrary to Barker's findings. This was possibly as a result of the more industrialised feed of Roundhill restricting the numbers of species. Reynoldson (1942) thought that protozoan species, in the activated sludge plant at Huddersfield, were limited in variety by the high percentage of chemical trade wastes in the sewage, though Curds and Cockburn (1970) found no evidence to suggest that protozoans are restricted by industrial wastes. The sparse populations of Carchesium polypinum would suggest less purified conditions in the Roundhill filters, but examination of the list of organisms found at Gospel End, but absent from Roundhill (Table 3.12. page 145) gives no indication why there was a comparatively restricted number of species at Roundhill; in fact Curds and Cockburn (1970) found Hemiophrys fusidens and Colpoda colpoda (missing from Roundhill) only in primary filters.

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A more likely reason for this species restriction at Roundhill would seem to be the accumulation of film. The sparsity of grazers during the first year allowed large amounts of film to accumulate. At times there were signs of septicity in samples taken from deep in the filters, especially in the summer months. This could have created conditions inimical to many potential protozoan colonizers. Surprisingly, the peritrichs Opercularia coarctata and Vorticella convallaria were the most abundant protozoans. In the second year, both microorganisms and macroinvertebrates had the greater proportion of their populations in the upper or middle parts of the filters, whilst the greatest film accumulations were found in the lower parts. Whether film accumulation was the reason for the lack of fauna, or whether it was the sparsity of fauna that enabled greater accumulation of film is difficult to determine.

The distribution and importance of nematodes in percolating filters has been comparatively little studied. Lloyd (1945) quoted Holtje (1943) as stating, that the presence of nematodes in filters was beneficial and that they stabilized much organic matter. Hawkes (1963) attributed discharges of humus solids from experimental filters, devoid of grazers, to the activities of the abundant nematode fauna. Murad and Bazer (1970) stated, that the populations of nematodes in filter film increased with decreasing temperature, though this referred to the warmer temperatures found in the southern part of the United States. The greatest nematode populations were found in spring or early summer in the Gospel End filter (Figs. 3.1. to 3.5.), but at various times in the Roundhill filters (Figs. 3.16. to 3.19.). There would seem to be an indirect correlation between the nematode populations and temperature through the effects of temperature on the activities of the grazers. Throughout the five year period that the Gospel End filter was studied, there was an inverse correlation between the abundance of nematodes and Metriocnemus larvae and, in late summer 1973, with Orthocladius larvae as well (Figs. 3.5. and 3.10.). At Roundhill, where the grazer populations were much sparser a comparatively vigorous nematode fauna developed, showing a fairly even distribution, little affected by the large accumulations of film.

Calaway (1968) studied rotifers in activated sludge processes and observed them fairly early in the development of an activated sludge, indicating tolerance to quite low purification levels. He stressed their importance in restricting bacterial populations, but doubted if they were as hardy as ciliates and found, that they took longer to become re-established once lost from the process. Rotifers were found in the filter at Gospel End one month after the start of operation and at Roundhill four months after the start. Although fairly common at Gospel End, they were rarely present in substantial numbers, whereas at Roundhill they were common for long periods, especially in the latter half of the second year. At both works, they were found throughout the depth of the filters, though at Gospel End there was a greater tendency for them to be found in the upper layers. Possibly a more profuse growth of bacteria, together with reduced competition from other microorganisms enabled greater populations of rotifers to develop at Roundhill.

The importance of a number of interacting factors upon the film and fauna of percolating filters was discussed in 1.1. Temperature has a direct effect both on the micro-organisms of the film (Barker, 1949; Hawkes, 1963) and on the macrofauna (Lloyd, 1937, 1943a, 1943b, 1945; Reynoldson, 1943, 1947; Golightly, 1940; Hawkes, 1960; Solbé, 1971). The strength of the feed, the organic loading, the rate of application of the feed, the type of medium and the frequency of dosing all have some effect on the degree of film accumulation (Tomlinson, 1941; Tomlinson and Hall, 1950; Terry, 1951; Hawkes and Jenkins, 1955; Hawkes, 1961 and 1963). The amount of film, in turn, has a direct effect on the fauna, as a source of food and in influencing the degree of aeration within the filter (Hawkes, 1963; Solbé, et al., 1967; Williams and Taylor, 1968; Hawkes and Shephard, 1972). Lastly, the macrofauna itself has a direct effect on restricting film growth (Lloyd, 1945; Terry, 1951; Hawkes, 1963, 1965b; Solbé et al., 1967; Hawkes and Shephard, 1972).

Lloyd (1937) reported, that there was no appreciable difference in the temperature at depths of 1 ft. (30 cm.) and 3 ft. (90 cm.). Continuous records of temperatures in the upper foot and at the four foot depth at Gospel End also showed, that temperature differences were minimal and so in Figs. 3.1. to 3.10. temperature has been represented by one set of readings, that recorded for the upper foot, in effect that of the filter feed.

Because of this barely discernible difference in temperature at various depths, only one probe was installed in each bed at Roundhill.

The results of the Gospel End survey (Figs. 3.6. - 3.10.) show, that the effect of temperature seemed to act directly on the insect species in determining their times of emergence. The main emergence of Metriocnemus took place in late spring 1970 (Fig. 3.12.) and 1971 (Fig. 3.13.), and early summer in 1972 (Fig. 3.14.) and 1973 (Fig. 3.15.). This later emergence in the last two years followed winters when numbers of Metriocnemus were much reduced (Figs. 3.8. and 3.9.). The reason for this reduction is thought to have been the greater accumulation of film induced by increased strength of feed, brought about by the reduction of recirculation, in October 1971, from a 2:1 ratio to a 1:1 ratio. The greater accumulation of film enabled a large increase in the numbers of enchytraeid worms to take place and presumably, also created conditions unfavourable to Metriocnemus. Hawkes (1963) maintained, that Metriocnemus prefers a clean filter. Lloyd (1937) found, that few larvae of Metriocnemus hirticollis survived below 4.5°C, but since the temperature in the Gospel End filter was rarely below 5°C for an appreciable time, it is unlikely that low temperatures had more effect than slowing down the metabolism. That Metriocnemus larvae had a profound effect on film accumulation is illustrated by the monthly histograms for the film and for Metriocnemus larvae and pupae. Greatest reductions of film coincided with peaks in the populations of Metriocnemus larvae, whilst greatest winter accumulations of film occurred during the winters when Metriocnemus larvae were reduced in number (Figs. 3.8. and 3.9.).

Except during the first year, when there was an extra peak, highest densities of larvae of Limnophyes were usually found at the same time as those of Metriocnemus, but the major peaks of adult emergence were usually later in the year than Metriocnemus. Lloyd (1937) also found that adult emergence was usually in late summer and stated that Limnophyes emerged later than the other insects, Psychoda spp. and Metriocnemus spp.

Orthocladius larvae became common only in late summer 1973 (Fig. 3.10.), when competition from Metriocnemus and Limnophyes larvae was much reduced.

Comparatively few insects emerged from the Roundhill filters, and peaks were minor, so that patterns of seasonal abundance could not be deduced with any certainty. That film accumulation has a marked effect on the success of chironomid larvae was shown by the fauna found in the Roundhill filters. Metriocnemus and Limnophyes were found in very small numbers there, probably because of large accumulations of film. During the second year, more Metriocnemus larvae were found in the upper layers, coinciding with film reduction (Figs. 3.18. and 3.19.).

Psychoda severini, according to Lloyd (1937), can survive lower temperatures than Metriocnemus can and so, provided conditions are suitable, it is able to increase during winter, when competition from other insect larvae is reduced. Also, its association with a thicker film growth, more usual in winter, provides adequate food (Lloyd, 1945). It was also found by Lloyd (1945) and by Solbé and Tozer (1971), that Psychoda larvae were more abundant in the top foot of the filter, where food was most abundant. In the Gospel End filter, Psychoda larvae were usually found where there was most film, but this was not always in the top foot. Possibly the predations of Metriocnemus and Limnophyes larvae near the surface depressed the Psychoda population there. Also the recurrent low-frequency dosing may have had the effect of pushing Psychoda further down, where the scouring action was less adverse. A similar depressive effect was found at Roundhill, where despite adequate food, competition from enchytraeid worms was a factor in allowing only small populations of Psychoda to develop. In January 1973, a larger population developed in filter 2 (Figs. 3.18.), when flow was stopped because of a mechanical breakdown. In filter 3 (Fig. 3.19.) most of the Psychoda larvae were found in the lower half of the filter, possibly because it was taking the force of the total flow to the filters. These populations probably comprised both Ps. severini and Ps. alternata larvae, since both species appeared as adults in subsequent months.

Lumbricillus (rivalis?) was generally the most successful of the macroinvertebrates at Roundhill, probably because the large amounts of film were more favourable to the development of enchytraeids than to including - Pallamala ?

insect larvae. At Gospel End, enchytraeids were found more abundantly during the colder months, especially when competition from insect larvae was reduced (Figs. 3.8. and 3.9.). Although found throughout the depth of the filters at both works, their greatest populations were usually found near the surface. Williams et al. (1969) found similar distribution patterns for Lumbricillus rivalis. Their density at Gospel End was usually inversely proportional to that of Metriocnemus larvae. A rather subdued migration downwards in spring and upwards in autumn, as described by Reynoldson (1939), could be discerned, though the effects of the increased activities of other grazers cannot be discounted. No migration was discernible in the Roundhill filters, possibly because there was no obvious time of sloughing.

Solbé (1971) found, that in an experimental filter lumbricids were not found until 10 months after the start of filter operation. No lumbricids were found at Roundhill, but at Gospel End lumbricids were first found six months after the filter was re-started. They gradually became more abundant over the duration of the study. Two species were distinguishable, Lumbricus rubellus and Eisenia sp., though these have been grouped together in the histograms (Figs. 3.6. - 3.10.). Terry (1951) and Solbé (1971) described annual rhythms of migration by lumbricids through the depth of the filter. Terry (1951) found that L. rubellus and E. foetida moved downwards in spring and returned to the surface in autumn, whereas Solbé (1971) found that in the top 3 ft. of a filter Eiseniella tetraedra and Dendrobaena rubida descended into the filter in early summer, returned in August and descended again in December. No obvious annual rhythms of this kind were observed in the Gospel End filter, possibly because the comparatively small numbers of worms involved made such movements either unnecessary or difficult to detect. Generally they were found more abundantly away from the surface. Also it is possible, that there was insufficient food in the filter to allow the development of large lumbricid populations.

Unfortunately, there was no means of measuring the frequency of dosing at Gospel End over prolonged periods, but from visual inspection during the working day, it appeared that there was a high periodicity for much of the day, often as frequently as once a minute. At night-time, however, and at other times of low flow, the rate of revolution of the distributors was decreased considerably, so that low frequency dosing was found at these times. However, the strength of the feed, although variable, was generally weak throughout, so that film accumulation for much of the period of investigation was low and in the 'clean' conditions so created Metriocnemus thrived. It was very noticeable, that when the strength of the feed increased in October 1971, due to reduced recirculation, Metriocnemus decreased in numbers, and film accumulation increased. Frequency of dosing at Roundhill was measurable throughout because the distributors are motor-driven. Periodicity was ten minutes for the first 5 months, but by the middle of June, it had been increased to 5.5 minutes. During the winter of 1972/73, it varied between 7.5 and 5.5 because of the occurrence of breakdowns, but by April it had returned to 5.5 minutes, and by June to 5.0 minutes. This regime of high-frequency dosing and consequently low rates of application from the beginning of the filter operation resulted in large accumulations of film, especially during the first year, when grazers were few in number. The use of low-frequency dosing to control film accumulation, especially in the early stages of filter operation, has been advocated by a number of workers (Tomlinson and Hall, 1955; Hawkes, 1955; Hawkes and Shephard, 1971, 1972). Low-frequency dosing at Roundhill, at least in the first year, would almost certainly have facilitated a quicker development of a macrofauna community.

Hawkes and Shephard (1972) found that Psychoda dominated a high-frequency dosed filter and chironomids a low-frequency dosed filter. In the present investigations, Psychoda dominated the impoverished insect fauna at Roundhill, but at Gospel End, Metriocnemus and Limnophyes were the dominant insect species, though this is thought to be as a consequence of the low organic loading. Psychoda could have found the times of low-frequency dosing unfavourable at Gospel End as well as finding a paucity of food. Probably a reduction in the number of filters being operated at Gospel End, with a consequent reduction in the degree of recirculation required, would not have resulted in any marked deterioration in the performance of the filters, and possibly little or no fundamental change in the composition of the fauna.

3.3.3. Filter efficiency

Tables 3.2. to 3.7. show the results of chemical analysis of 8 hour composite samples taken at Gospel End. These indicate that despite fluctuations in amount and point of introduction of recirculation, and in the number of filters being used, there was little difference in the results obtained from month to month, except for expected seasonal differences. The final effluent was poorly nitrified during March and April 1969, whilst the filters were being cleaned and immediately after. By June, when a considerable fauna had become established (Fig. 3.6.), nitrification had increased appreciably (Table 3.3.), though this was probably as a result of increased temperature rather than the decrease of film to an optimum thickness due to grazer activity. Because of a weak feed, film accumulation was not a problem even in winter.

Comparison of Tables 3.9. and 3.10. show that within a few months of the start of operation of the Roundhill works, there was a considerable improvement in the quality of the final effluent, compared with that discharged from Roundhill Farm during the previous year. Tables 3.10. and 3.11. show that although the BOD of the settled sewage was 'average', the N/8 PV was fairly strong at times, indicating a proportion of waste of industrial origin. There seems to have been little reduction in BOD in the secondary filter, but a considerable reduction in the primary filter. By September 1972 (Table 3.10.) an appreciable degree of nitrification was apparent, despite the large accumulations of film.

There was a surprising similarity in the figures from the two works for total metals and zinc content of the final effluent (Tables 3.3. - 3.11.) considering the different nature of the waste to the two. Although the results for metals analysis were higher for Roundhill, those for Gospel End seemed comparatively high for a domestic waste.

3.4. Conclusions

A five-year study of a single filter receiving part of its feed as recirculated effluent, and a two-year study of two filters operating on the ADF system, have revealed the following aspects of operation and of film and fauna variation.

(1) Proximity to other operating filters was of little or no advantage in the establishment of the microfauna. Nematode worms and peritrich ciliates were the dominant members of the microfauna at both works.

(2) The extent and density of microfauna was affected by the activities of the grazing fauna, especially of chironomids.

(3) *Vorticella convallaria* and *Opercularia coarctata* were adversely affected by breakdowns at Roundhill, but nematodes were unaffected.

(4) Twice as many species of microorganisms were found at Gospel End as at Roundhill, where extensive film accumulation was unfavourable to protozoan colonization.

(5) The proximity of an operating filter was of some advantage in the colonization of the Gospel End filter by macrofauna though the considerable film accumulation at Roundhill may have been a disadvantage in this respect. Chironomids were adversely affected by film accumulation all the time at Roundhill and sometimes at Gospel End.

(6) As temperatures rose, chironomids were important in restricting film growth. *Psychoda* congregated where there was more film present and was more important in the colder months.

(7) *Lumbricillus* was active in restricting film growth at Roundhill, especially in the second year. It was usually more common in the upper parts of filters and at Gospel End was inversely related in abundance to *Metriocnemus* larvae.

(8) High-frequency dosing at Roundhill was probably primarily responsible for the accumulation of film. Variable dosing with a weak feed led to a *Metriocnemus*-dominated fauna at Gospel End for much of the time. Decreased recirculation, resulting in a stronger feed, led to greater film growth, which coincided with a decrease in the *Metriocnemus* population.

(9) The chemical results indicate considerable purification in the ADF at Roundhill, but there was no indication of this efficiency from the film and fauna.

4. Ecological studies on the effects of polluting effluents on streams

4.1.1. Methods

It was shown in section 2.2. that the River Stour, within the area studied, can vary considerably in depth between less than 3 in. (8 cm.) to several feet depending upon the flow and the station. The quantities of rubbish found where the streams flow through built-up areas made any method of sampling difficult. After a theoretical assessment of the methods described in section 1.4., it was decided to use a modification of the Hynes kick method. This method, like all the other methods, is selective and gives rise to errors, but it has the merits of simplicity, adaptability and rapidity in use.

The net used for sampling had a triangular opening with 8 meshes/cm. (20/in.) as supplied by the Freshwater Biological Association. It was decided to sample a specific area, so that a closer comparison could be made between samples taken from different stations and between successive samples at any one station. The width of the net was 12 in. (30.5 cm.) so that when the area upstream of the net was disturbed to a distance of 1 ft. one square foot of substratum was sampled. Ten such sampling units were included, so that an area of approximately 1 m^2 (10 $ft.^2$) could be sampled. This was thought to be a valid area-size for comparison both within the survey and with other workers' results. Each sampling unit area was thoroughly disturbed with the foot in a downstream direction in front of the net, starting at a distance of

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1 ft. from the net, thus, any animals which had settled back quickly on to the stream bed were probably disturbed again. It was found that with practice this could be done both in turbid water and also in fairly deep water (2 ft.).

When possible, the station was inspected visually first, to estimate the extent of different habitats and the approximate percentage cover by weeds, and then it was sampled accordingly; for example, if the estimated weed cover was 50% then 5 of the sample units were taken in the weed habitat. Sampling was done on diagonal transects taking into account the proportions of different micro-habitats, though some care was taken to try to ensure that the station habitat was reasonably uniform. Bourdeau (1953) showed that a method of stratified random sampling was more accurate than either unrestricted random sampling or systematic sampling in assessing a non-randomly distributed community, i.e. each strata or habitat is sampled according to its area within the station. Where the riffle was fairly uniform or when the water was turbid, sampling units were taken about 1 ft. apart on a series of diagonal transects, the number of transects depending upon the width of the river. No units were located close to the banks nor at either end of the riffles where, because of slower current velocities, animals typical of depositing substrata might be expected to occur and thus possibly give a bias to the results. (See section 4.1.2., page 169).

At each station a note was made of the range of width and depth of the stream. The temperature was measured and the colour and clarity of the water assessed. The current velocity was estimated at first by measuring the time taken for a semi-submerged object, a small piece of wood, to travel one metre. Towards the end of the survey period an Ott current velocity meter was obtained with which measurements were made at three points close to the substratum. The nature of the substratum was observed and the extent of weed cover assessed. The presence of fish or of sewage fungus was noted. Also as facilities and equipment became available the pH and dissolved oxygen content of the water were measured and samples were taken for metals analysis.

Various methods of sorting and separating the fauna from the stones and debris have been developed. Some methods involve the principle of flotation of the animals in a solution of calcium chloride or in a weak solution of HCl in 2-5% alcohol, but these methods suffer from the fact that molluscs and cased caddis larvae do not float and so have to be sorted out afterwards from the debris. Other methods involve washing the sample in a sieve or in a series of sieves in order to remove the very fine material.

The samples from this survey were washed in two sieves, one of 10 meshes/in. (4 meshes/cm.) placed on top of another one of 60 meshes/in. (24 meshes/cm.). The washed sample was then placed in a large, white enamel tray and the number of each species were counted, using a series of tally counters. It was found that even a sample containing a large number of species and individuals could be sorted and counted quickly using this procedure. Where there was a very large number of any species, e.g. Potamopyrgus jenkinsi at stations 23 and 29, the sample was thoroughly mixed, then spread evenly in the tray and divided into a number of equal portions. The number of the species found in two portions was counted and then the mean of the two was multiplied by the number of portions to give an estimate of the total. Species found in only small numbers in such samples were counted in the usual way. When possible the samples were sorted live, otherwise after a quick inspection of the species present, they were preserved in a weak solution of formaldehyde for later examination.

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4.1.2. Preliminary investigation of the sampling method to determine intra-riffle distribution of macroinvertebrates.

As explained in 4.1.1. sampling was done on diagonal transects, taking into consideration microhabitats, in an attempt to overcome the non-random distribution of fauna across the riffle and more especially along the riffle. As an exercise, stations 1 and 7, both of which have a fairly uniform substratum, were sampled on diagonal transects and the fauna collected from individual sampling units was put into separate jars. More than three transects were made at station 1 and two at station 7, where the river was wider. Sampling units were numbered from one to 10, working upstream.

Sampling units were also taken at the upstream and downstream ends of the riffle and close to the banks. Tables 4.1. and 4.2. show the results of this exercise.

The non-random distribution of the fauna was particularly noticeable at station 1. (Table 4.1.). It can be seen that _Potamopyrgus jenkinsi_ was most abundant near the downstream end of the riffle (units 1 to 3) and at the downstream and upstream extremities of the riffle (units 11 and 12). The maximum diameter of the stones was about 2 cm. at units 1, 2, and 3 and at units 11 and 12 the material of the bed was finer. _Baetis rhodani_ was dominant further upstream (units 4 to 8) where somewhat larger stones were found. It was rare in the silty parts (units 11 to 14). _Gammarus pulex_ was more common in midstream and towards the left bank and was rare in the silty parts, except at unit 14 near the left bank, where more detritus had accumulated. Close to the banks (units 13 and 14) chironomid larvae were dominant.

At station 7, where the river was polluted, the fauna was more restricted in numbers, but the longitudinal and transverse distribution of species was more even. Except for unit 1 (Table 4.2.) where there was possibly a greater proportion of silt, _Asellus aquaticus_ was the dominant species in each unit. Even in units 11 to 14 _Asellus_ was dominant or co-dominant, but tubificids were generally more common in these units than they were elsewhere.

The efficiency of the sampling method in including all the species present may be estimated from an

Tubificidae	3	9	3	12	15	10	10	8	-	2	7	1	1	3
Lumbricidae	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Naididae	7	8	2	18	26	13	5	19	1	13	7	1	1	2
Glossiphoniidae	-	-	1	-	-	-	-	-	2	-	-	-	-	-
Gammarus pulex	7	3	14	35	22	8	6	33	21	15	1	3	-	10
Baetis rhodani	16	18	23	52	56	27	17	34	-	11	1	1	1	-
Trichoptera	-	-	2	1	-	-	-	2	-	-	-	-	1	-
Coleoptera	1	-	6	2	1	3	-	2	-	-	4	3	1	1
Chironomidae	24	10	6	19	8	7	3	6	3	10	47	16	22	29
Tipulidae	-	-	4	-	1	1	-	2	-	-	-	2	-	-
Other Diptera	1	-	1	1	-	-	-	-	-	-	-	-	-	-
P. jenkinsi	308	201	97	32	48	11	9	49	49	6	90	109	2	1
Pisidium	-	-	1	1	-	-	-	-	-	-	3	-	-	1
No. of Animals	367	249	160	173	177	80	50	155	76	57	161	136	29	47
No. of Species	7	6	12	10	8	8	6	9	5	6	9	8	7	7

Midstream - Units 2,5,8,10
Left of Midstream - Units 3,4,9,
Right of Midstream - Units 1,6,7

Upstream of riffle -Unit 12
downstream of Riffle Unit 11
Close to right Bank Unit 13
Close to left Bank Unit 14

Table 4.1 Numbers of Macroinvertebrates found in sampling units at Station 1

Tubificidae	58	7	2	2	1	-	1	2	2	2	33	18	15	5
Enchytraeidae	-	-	2	4	2	6	6	5	7	5	8	-	-	-
Naididae	13	1	11	5	5	2	4	3	13	3	-	-	-	-
Erpobdellidae	-	-	2	-	-	-	-	-	-	-	1	-	3	-
Asellus aquaticus	29	10	12	46	10	19	26	9	9	30	126	17	122	20
Chironomidae	8	1	6	3	1	2	3	8	1	-	24	3	6	3
P.jenkinsi	1	-	-	-	-	-	-	-	-	-	-	-	3	-
Limnaea pereger	32	7	9	8	2	2	9	4	2	7	49	7	30	2
Physa fontinalis	-	1	1	-	-	-	-	-	-	-	-	-	-	-
No.of animals	141	27	45	68	21	31	49	31	34	47	241	45	176	30
No.of species	6	6	8	6	6	5	6	6	6	5	6	4	5	4

Midstream - Units 3 and 8
Right of midstream - Units 2 and 9
Further right of midstream - Units 1 and 10
Left of midstream - Units 4 and 7
Further left of midstream - Units 5 and 6

Downstream of riffle - Unit 11
Upstream of riffle - Unit 12
Close to right bank - Unit 13
Close to left bank - Unit 14

Table 4.2. Numbers of macroinvertebrates found in sampling units at Station 7.

examination of Tables 4.1. and 4.2. When considering the total species found in each sample, that is in ten sampling units, at both stations all the species found in the ten units had been found by unit 3. At station 1, the commonest species, Gammarus pulex, Potamopyrgus jenkinsi and Baetis rhodani formed the bulk of the fauna by unit 3, and at station 7 the commonest groups, Asellus aquaticus, Naididae and Limnaea pereger were encountered in unit 1. This method, that is the Hynes kick method, was, therefore, considered efficient for assessing community composition.

I do not think you can conclude this. All you can conclude is that it picked up all the taxonomic groups that you determined. Most of these were not taken beyond the family level & probably can't measure abundance effectively.

4.2. Results and Discussion

The detailed results for all the stations sampled between July 1967 and June 1973, including various physical and chemical parameters measured, are contained in the Appendix Tables 1. to 131. The data from the biological surveys have been interpreted using three biotic indices, namely the Trent Biotic Index, the Chandler Score and a Diversity Index. Identification of macroinvertebrates was made by reference to Michaelsen and Johansson (1909), Macan (1959, 1960, 1961 and 1970), Bryce (1960), Hynes et al. (1960), Mann (1964), Kimmins (1962), Reynoldson (1967), Hynes (1967), Davies (1968) and Brinkhurst (1971).

4.2.1. General distribution of specific invertebrates in the catchment area

The distribution in the River Stour is shown by histograms in Figs. 4.1. to 4.6. Tubificids and enchytraeids were grouped together at first, but when

Fig. 4.1. Histogram showing mean number of animals distributed along the River Stour 1967-1968

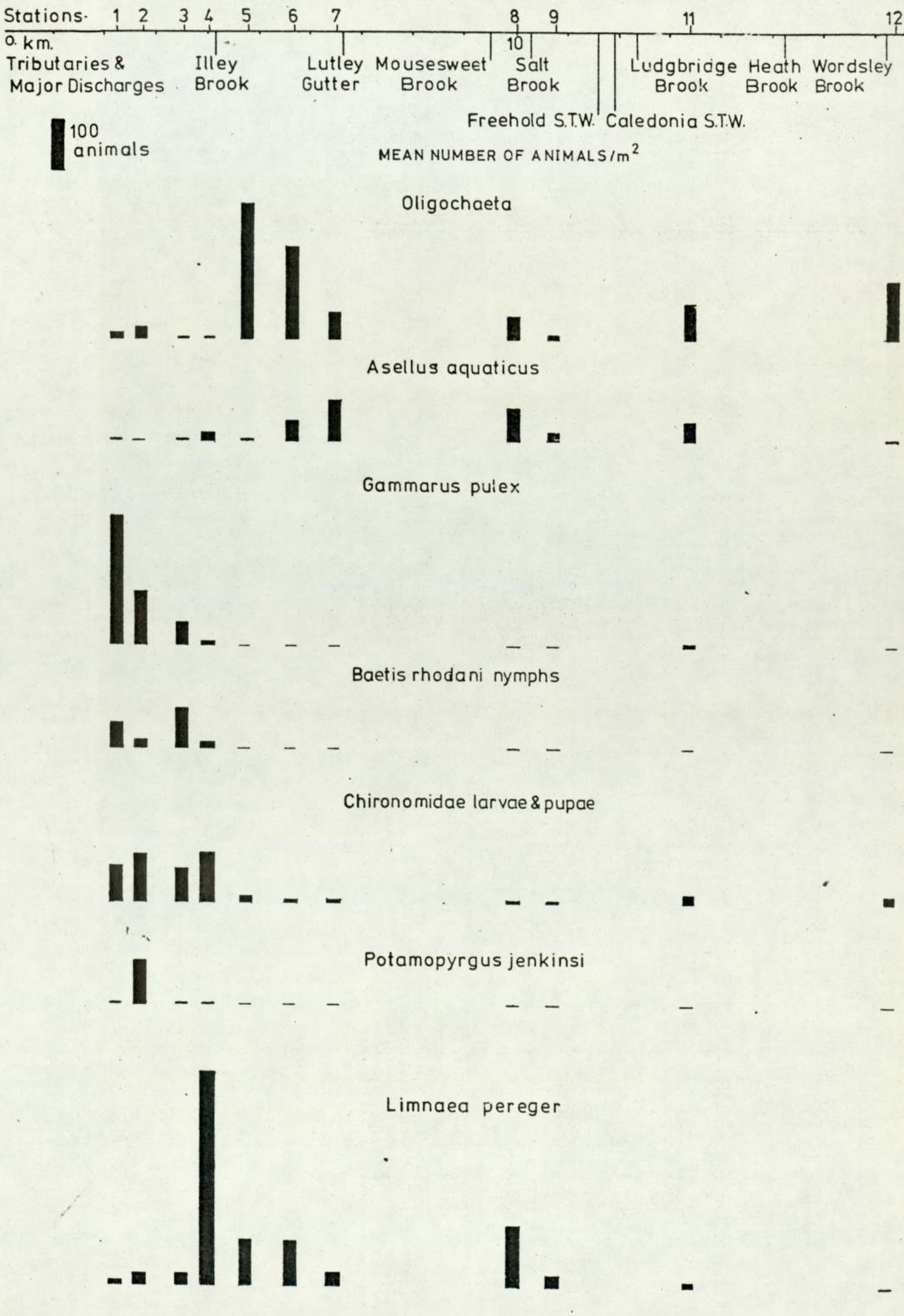


Fig. 4.2. Histograms showing mean numbers of animals distributed along the River Stour 1968 - 1969

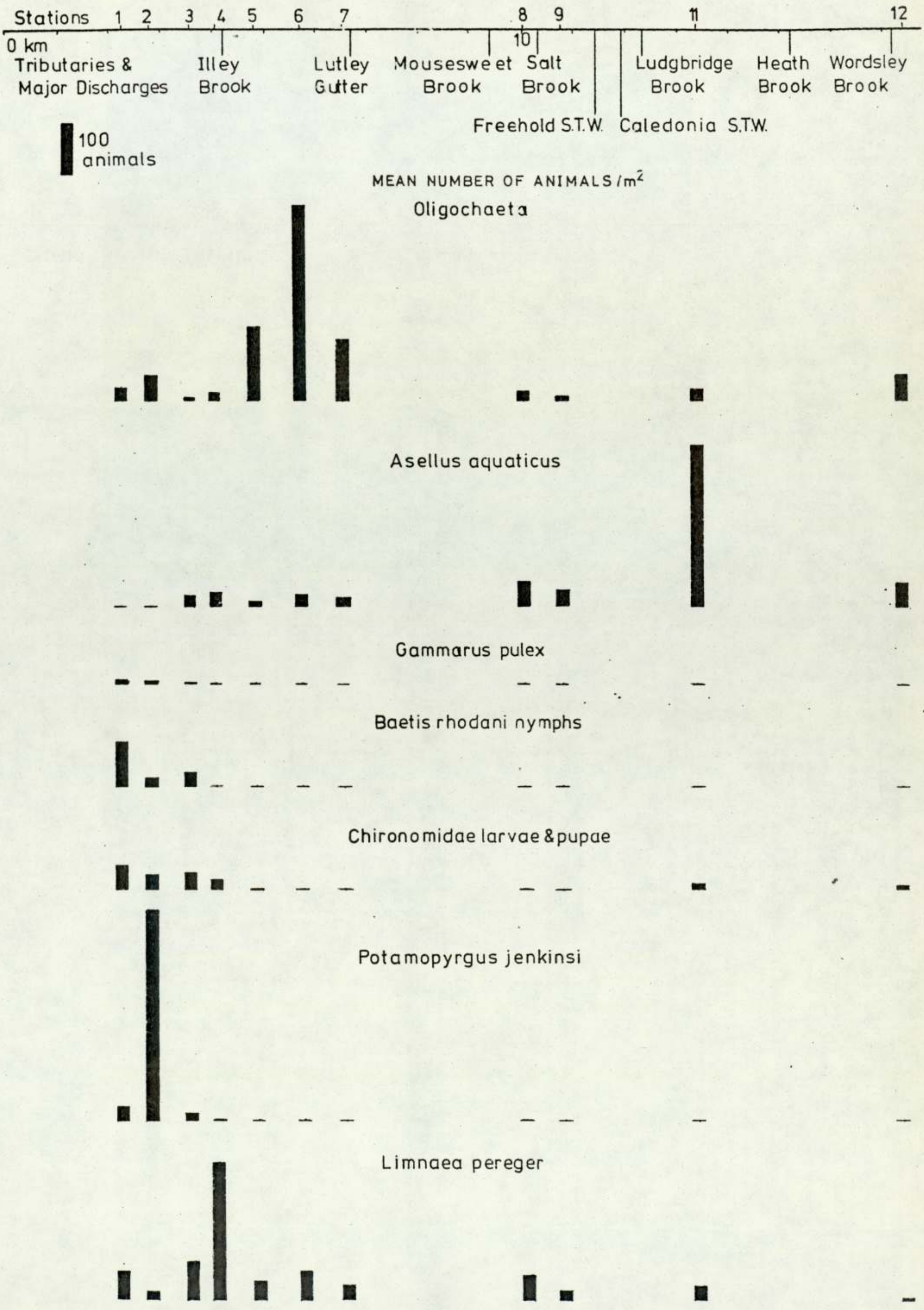


Fig. 4.3. Histograms showing mean number of animals distributed along the River Stour 1969-1970

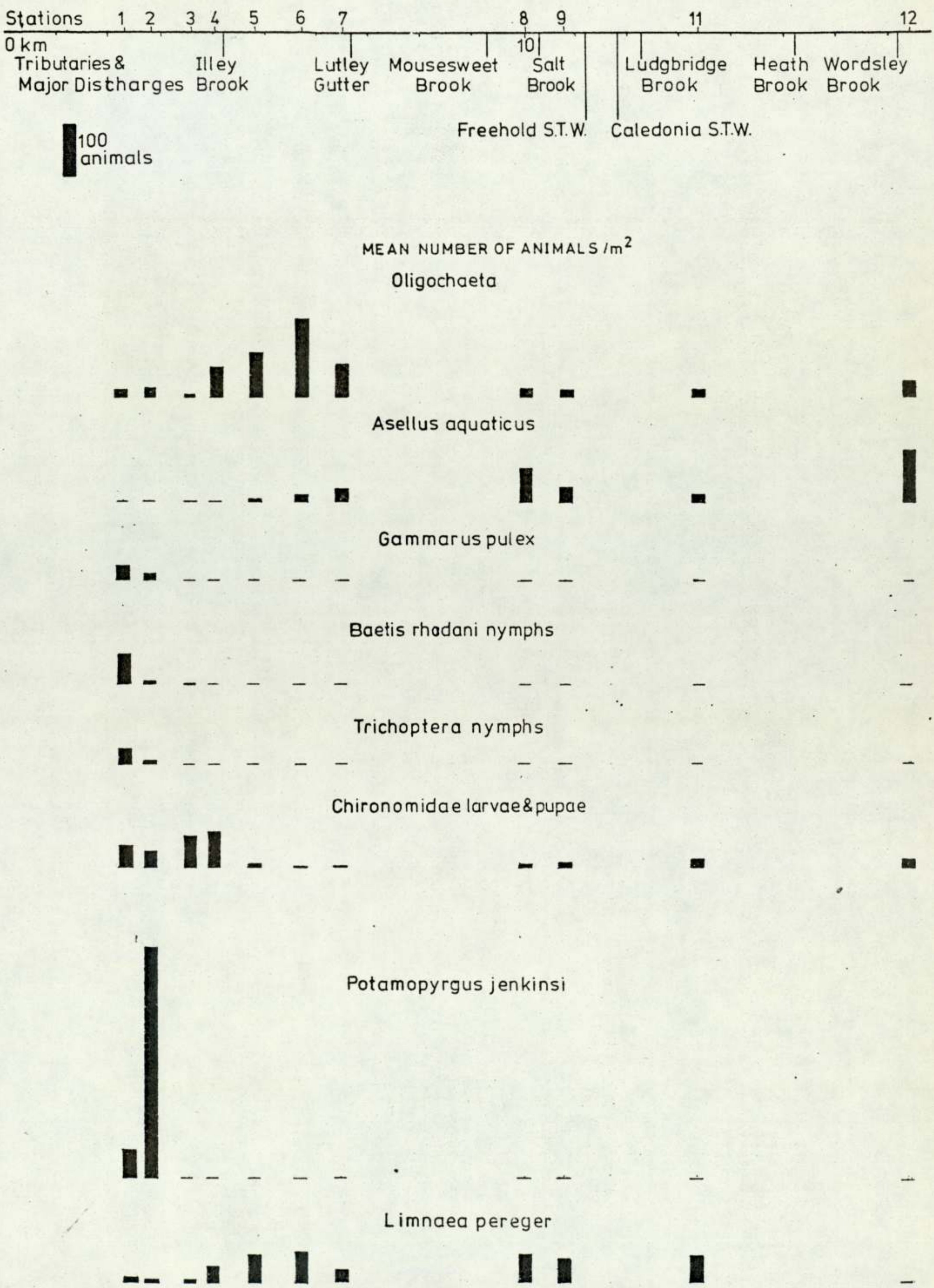


Fig. 4.4 Histograms showing mean number of animals distributed along the River Stour 1970-1971

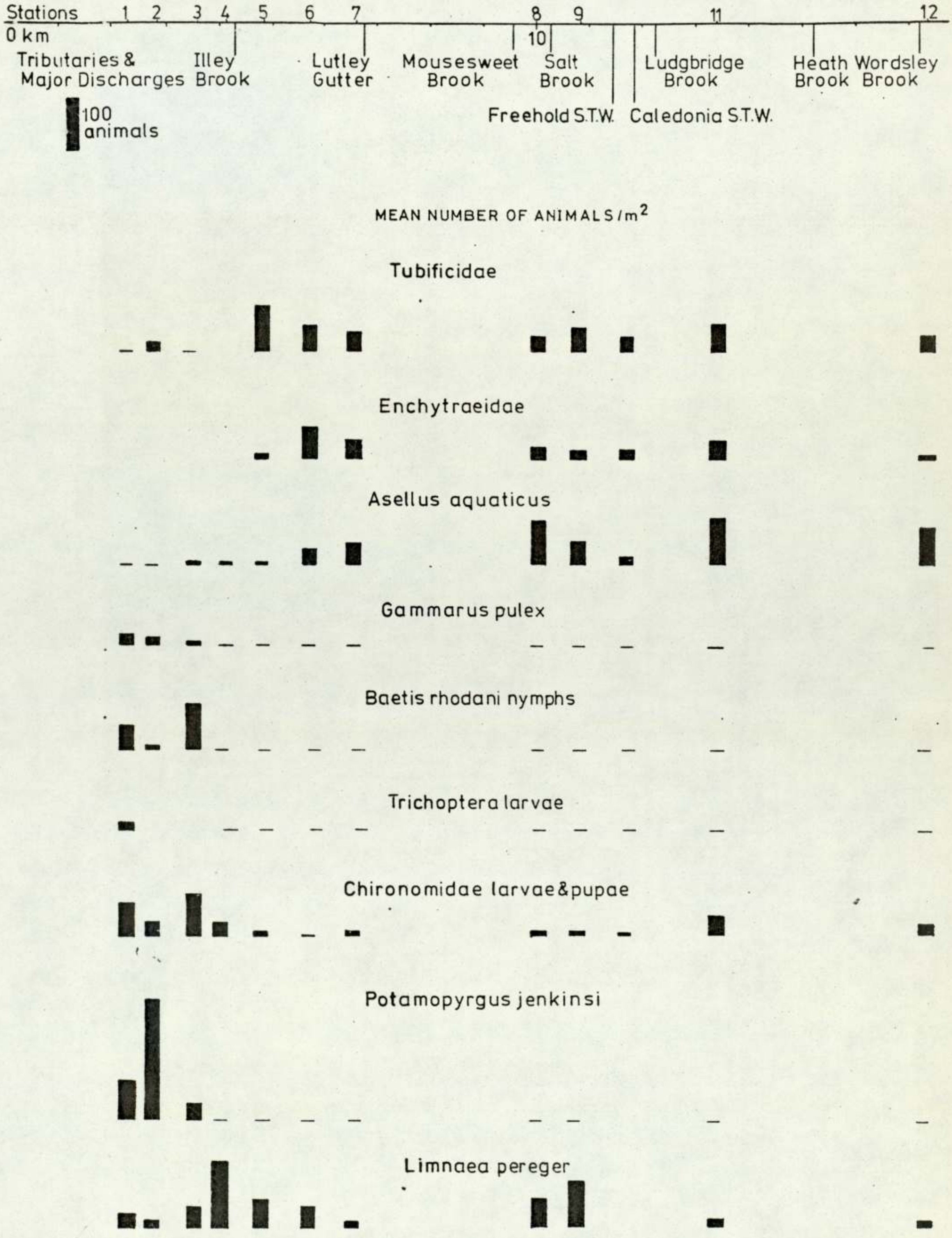


Fig.4.5. Histograms showing mean number of animals distributed along the River Stour 1971-1972

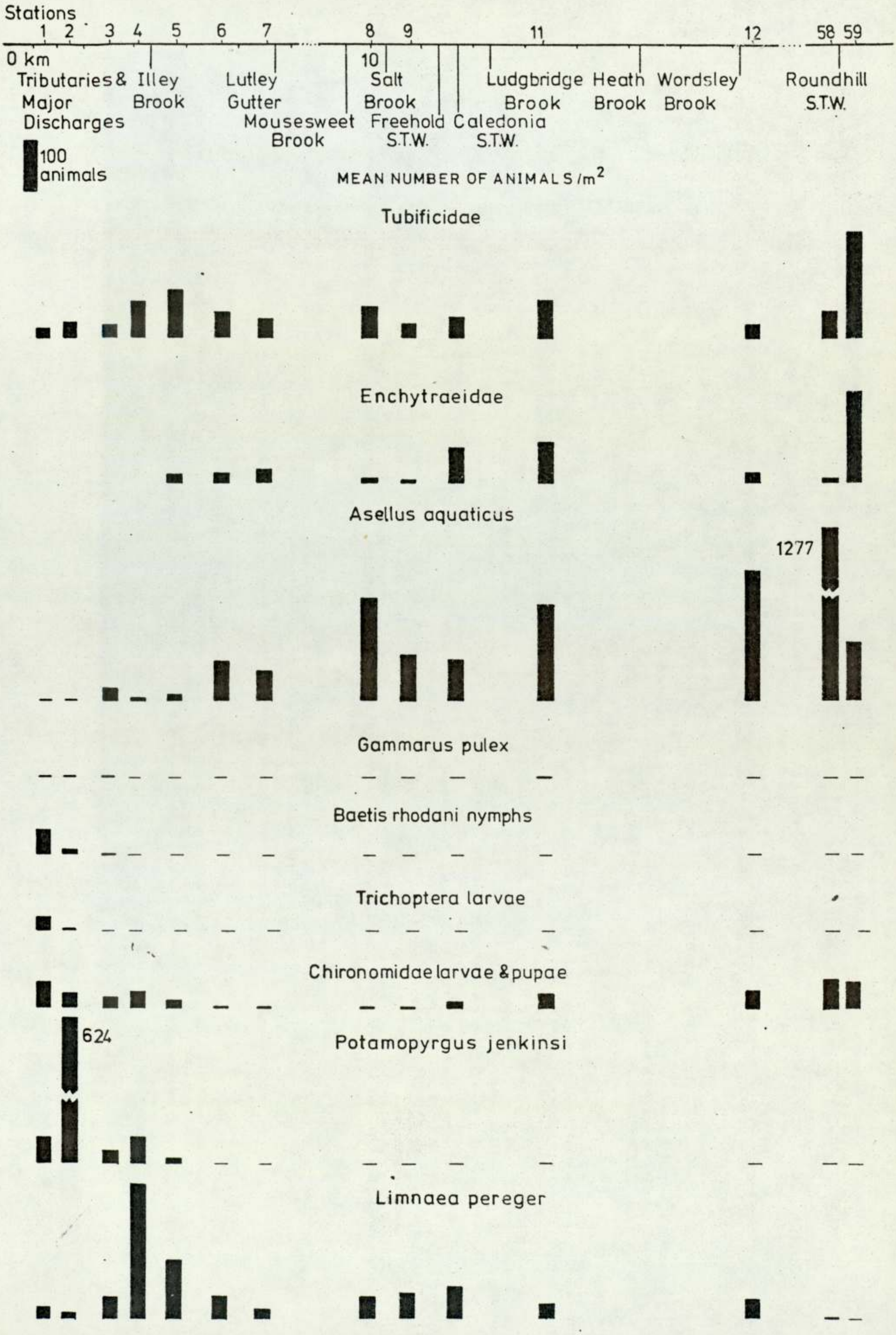
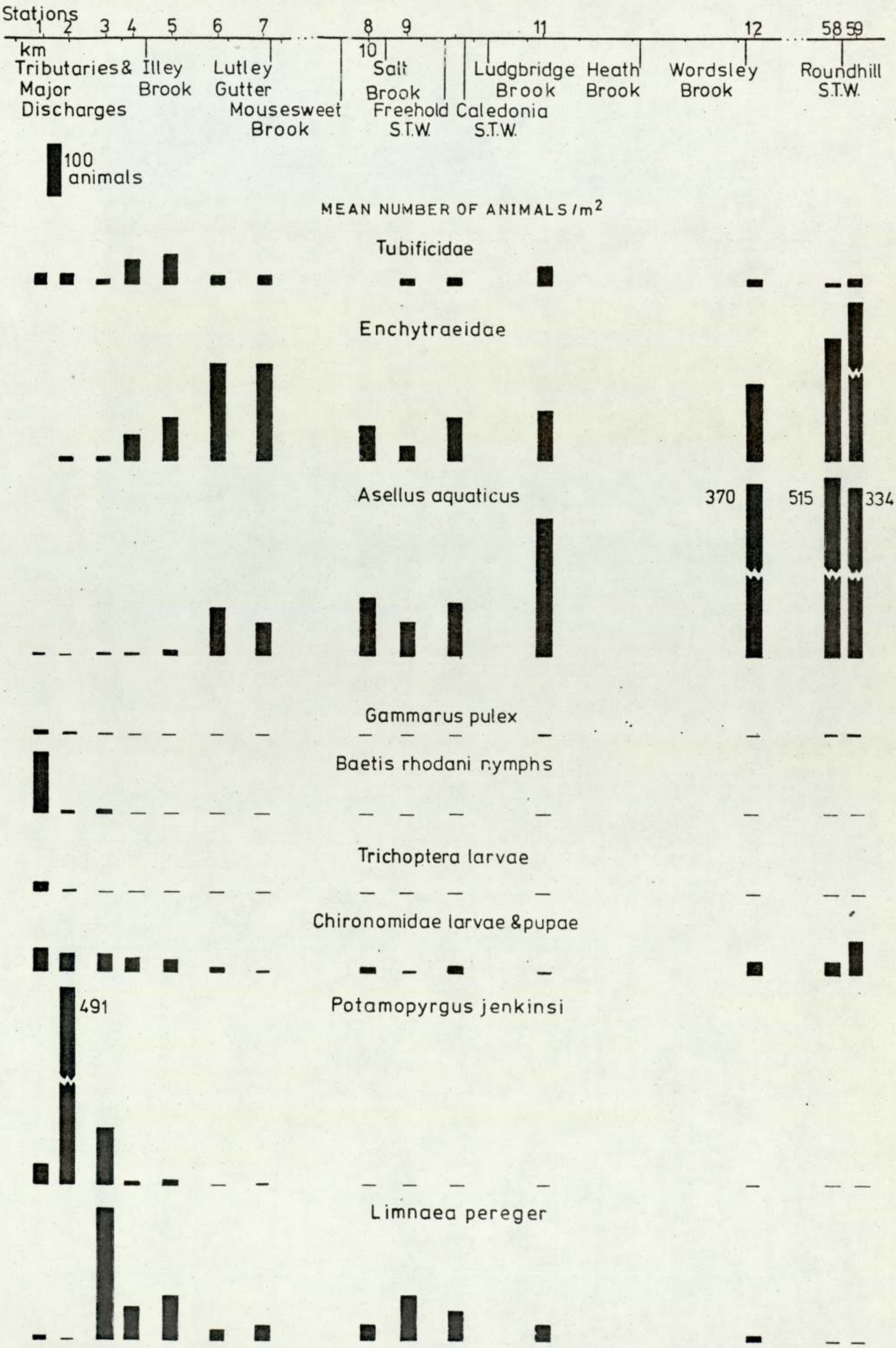


Fig.4.6. Histograms showing mean number of animals distributed along the River Stour 1972-1973



the key by Brinkhurst (1971) became available they were counted separately. Although tubificids were found at all the stations, they occurred in large numbers only in the polluted stretches and even there their numbers varied from year to year or month to month. They were found most abundantly in the River Stour at stations 5, 6, 7 and 59, at station 14 in Illey Brook and at station 56 in Dawley Brook. They were commonly found in the River Stour at stations downstream of Halesowen, in Mousesweet Brook and in Bob's Brook. Enchytraeids showed a similar general distribution, but were usually most abundant either before or after the time of peak abundance of tubificids.

Asellus aquaticus was found in most streams, except Lutley Gutter and Ludgbridge Brook. It occurred at most stations in the Stour, but mainly at stations 6, 7, 8, 10, 11, 12 and 58. Its greatest abundance, however, was in Holbeache Brook at station 35, where it was the dominant macroinvertebrate for most of the study period.

At a number of stations, Gammarus pulex was dominant either over the whole period 1967-1973 or part of it. This distribution was particularly prevalent in Lutley Gutter, Ludgbridge Brook, station 55 in Dawley Brook, stations 49 and 54 in Bob's Brook, station 50 in Holbeache Brook, station 36 in Penn Brook and for short periods at station 1 in the River Stour. It was poorly represented in the Stour at any station downstream of Halesowen, except for station 11 where it occurred sporadically but did not become established.

Baetis rhodani was found to be common at a number of stations, notably station 1 on the River Stour and at some stations on Illey Brook, Lutley Gutter, Ludgbridge Brook and Penn Brook. Sometimes it was dominant, often co-dominant but usually sub-dominant compared with Garmmarus pulex.

Chironomus riparius was found occasionally at a number of stations, but it occurred in its greatest numbers, for short periods, at station 14 (Illey Brook) and at stations 26 and 27 (Wordsley Brook). Although a distinction was made between the other chironomids, they were not individually identified to species and so have been grouped together. They were found most abundantly at stations 13 and 14 on Illey Brook, and somewhat less abundantly between stations 1 and 3 on the River Stour.

Simulidae larvae were found in seasonal abundance only in Penn Brook at stations 37 and 38, downstream of the discharge from Gospel End Sewage Treatment Works. They were commonly found from time to time in Bob's Brook and Holbeache Brook, but were found only rarely elsewhere.

The snail, Potamopyrgus jenkinsi considerably increased its distribution range in various water-courses during the period 1967 to 1973. In 1967, P. jenkinsi was abundant and usually dominant at station 2 on the Stour, but by the end of the survey period, it had extended its distribution both upstream to station 1 and also downstream to station 3. It also occurred abundantly in Dawley Brook at stations 29 and 31, but its greatest occurrence was in Saltwells Brook at station 23 and Black Brook at station 52.

The other commonly occurring snail, Limnaea pereger, showed its greatest frequency in organically polluted streams. It was fairly common throughout the Stour except at station 59, but was most abundant at stations 3 and 4, at the times when this stretch of the river was subject to organic pollution. Its distribution in the tributary streams was widespread but not in large numbers.

In an industrialised system such as that of the River Stour and many of its tributaries, it was often difficult to find suitable sections of riffle in which to study the biota. In much of the area, especially in the stretches flowing through Cradley and Stourbridge, where old-established industry bordered both banks, access to these parts was often impossible. At times the accumulation of rubbish, especially bricks, necessitated moving the position of some stations a short distance (stations 4, 18, 20, 24, 26, 28 and 49). These accumulations often resulted in a decrease of flow at the riffle resulting in greater deposition of finer material, thus altering the ecology of the riffle. Station 54 (Bob's Brook) had to be moved upstream when the original site was culverted.

Besides these unnatural factors, a number of natural parameters needed to be taken into account, when assessing the state of a stream at a particular station. For example, high flows can have a profound effect on the benthic fauna both in removing some species and in introducing others. This can have a considerable effect on the correct interpretation of survey results. Jones (1951) found, that flooding in the River Towy resulted in a reduction of the invertebrate community from 300-1000/0.25 m^2 to 40-48. Also, the stability of the substratum affects the colonization of the riffle, unstable substrata offering a poor habitat to many species. Amongst loose stones, Percival and Whitehead (1929) found that the proportion of Rhithrogena rose, whilst that of chironomids fell, whereas where the stones were embedded in the substratum chironomids, Ancylus sp., Limnaea sp., Agapetus sp. and Polycentropus sp. were favoured. Furthermore, amongst stones covered with Cladophora chironomids, naid worms, Ancylus sp. and Limnaea sp. were common but Rhithrogena, Agapetus and Glossosoma were rare. Because of variations in flow and deposition of rubbish and debris, the substratum of stations 6 and 9 became unstable during the study period. The width of the bed was found by Hawkes (1963a) to affect the fauna of the riffle, narrow streams having a poor fauna. The width of the stream at stations 49 and 54 was often very narrow, sometimes less than 60 cm. wide, but these stations were retained as a means of comparison with stations further downstream and because of intermittent polluting discharges near station 54.

4.2.2. Initial Survey

The results from the first monthly survey of the

River Stour, in July 1967, showed that the river was clean upstream of and part of the distance through Halesowen (stations 1, 2 and 3), but that downstream of the town it received a number of polluting discharges so that at station 12 (the station furthest downstream at that time) tubificid worms comprised 98% of the fauna. Another evident aspect was that the counts of animals were small (Appendix Tables 25, 31, 37, 43, 49, 57 and 63) even where the fauna was completely dominated by one species, so evidently the polluting discharges were not only organic in nature but also toxic. Sources of pollution at this time included a surcharging foul sewer to the Coombeswood tributary which joins the river just upstream of station 5, a foul-sewer washout downstream of station 6, occasional overflows from storm tanks at Bellevale and Cradley Forge, a foul-sewer overflow at station 8, polluting discharges to Salt Brook which joins the river between stations 8 and 9, polluting discharges to a culverted stream (Bromley Street culvert) entering the river at station 9, the effluent from Caledonia Sewage Treatment Works about 1.5 km upstream of station 11, various discharges in the industrial area of Stourbridge, and discharges of waste to Coalbourn Brook, Audnam Brook and Wordsley Brook which join the river upstream of station 12.

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At stations 1, 2 and 3 a varied fauna was found including *Gammarus pulex*, *Baetis rhodani* and at station 3 caddis larvae, but dominated by chironomids, possibly due to the partial emergence of the baetid population

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and to the suitable substratum (Appendix Tables 1, 7 and 13). Chironomids were even more evident at station 4, _Asellus_ had appeared and _Limnaea pereger_ was present in large numbers (Appendix Table 19). The _Gammarus_ and _Baetis_ populations were comparatively reduced here. The source of pollution upstream of station 4 was a surface water sewer receiving discharges of waste liquid. A drastic change in the riffle fauna was found at station 5, where the Coombeswood tributary, which was receiving surcharges from a foul sewer and the effluent from ill-funtioning settlement tanks at a steel works, entered. This pollution resulted in the disappearance of _Gammarus_, _Baetis_ and _Asellus_ and the reduction of the chironomid and _Limnaea_ populations. Conversely the tubificid population was greater than that upstream, though its comparatively small size suggested that toxic wastes were present (Appendix Table 25)

No improvement was found at station 6 (Appendix Table 31), but at station 7 a small number of _Asellus_ and of chironomid larvae had re-appeared (Appendix Table 37). Because of the siting of factories along the banks in Cradley, station 8 was about two miles downstream of station 7, Between the two stations the river received occasional overflows from Bellevale and Cradley Forge storm tanks, intermittent discharges from factories and about $\frac{1}{4}$ mile upstream of station 8, Mousesweet Brook. A sparse fauna was found at station 8 dominated by tubificids and comprising also _Asellus_, _Erpobdella_, chironomids and _Limnaea_, indicating that there had been some deterioration since station 7 (Appendix Table 43). At station 9, even fewer animals were found, Erpobdella, chironomids and Limnaea totalling nine individuals (Appendix Table 49). It is possible that silt accumulated around banks of Potamogeton pectinatus had some adverse effect, though it is more likely that discharges, containing toxic metals, to Salt Brook and the Bromley Street culvert had a greater effect. Station 10 had not been established at the time of this first survey, and it was possible to take only a qualitative sample at station 11 which showed that tubificids, Asellus and Limnaea were present. This showed that a certain amount of improvement had occurred downstream of station 9, but at station 12 a fauna dominated, though in small numbers, by tubificids showed that further polluting discharges, some of them toxic, had entered the river upstream (Appendix Table 63).

This preliminary survey showed, therefore, that the river upstream of Halesowen was clean, but that successive polluting discharges downstream of the town had a serious effect on the riffle fauna. It is not feasible to describe in detail the changes which occurred at each station over the following seventy months, but a description of the detectable effects of pollutants would illustrate the magnitude of the pollution load of the River Stour and its tributaries.

4.2.3. Monthly Surveys 1967-1972

The mean composition of the benthic fauna for each 12 month period during the six-year study is shown in

Figs. 4.7. to 4.12 (pages 188-193)

Stations 1 & 2 (River Stour, upstream of Halesowen).

The benthic fauna upstream of Halesowen was that associated with clean water (Hynes, 1960; Hawkes, 1963) comprising a comparatively large number of species including mayfly and caddisfly species, though at station 2 the fauna was usually dominated by *Potamopyrgus jenkinsi*. The only sources of possible pollution upstream of stations 1 and 2 were farm- and road-runoff. The increase in number of *Potamopyrgus*, which is believed to be tolerant of slight pollution (Hawkes, 1963), may be indicative of occasional discharges of a mildly polluting nature (Appendix Tables 1-12).

Station 3 (River Stour, Halesowen).

The fauna at station 3, situated downstream of Great Cornbow, Halesowen, was subjected to a variety of polluting discharges during 1967 to 1973 (Appendix Tables 13-18). The first surveys showed that the river here supported quite a varied, clean-water fauna including cased caddis larvae (Fig. 4.7, page 188). High flows in November 1967, however, eliminated a declining caddis population and in March 1968 the community was further restricted by polluting discharges via a surface water sewer upstream. Although *Baetis rhodani* was found in appreciable numbers by July, *Gammarus* was sparse and by November had been replaced by *Asellus aquaticus*. *Baetis rhodani* had also disappeared by November but a few caddis larvae were still to be found. Worsening conditions brought about by a surcharging foul-

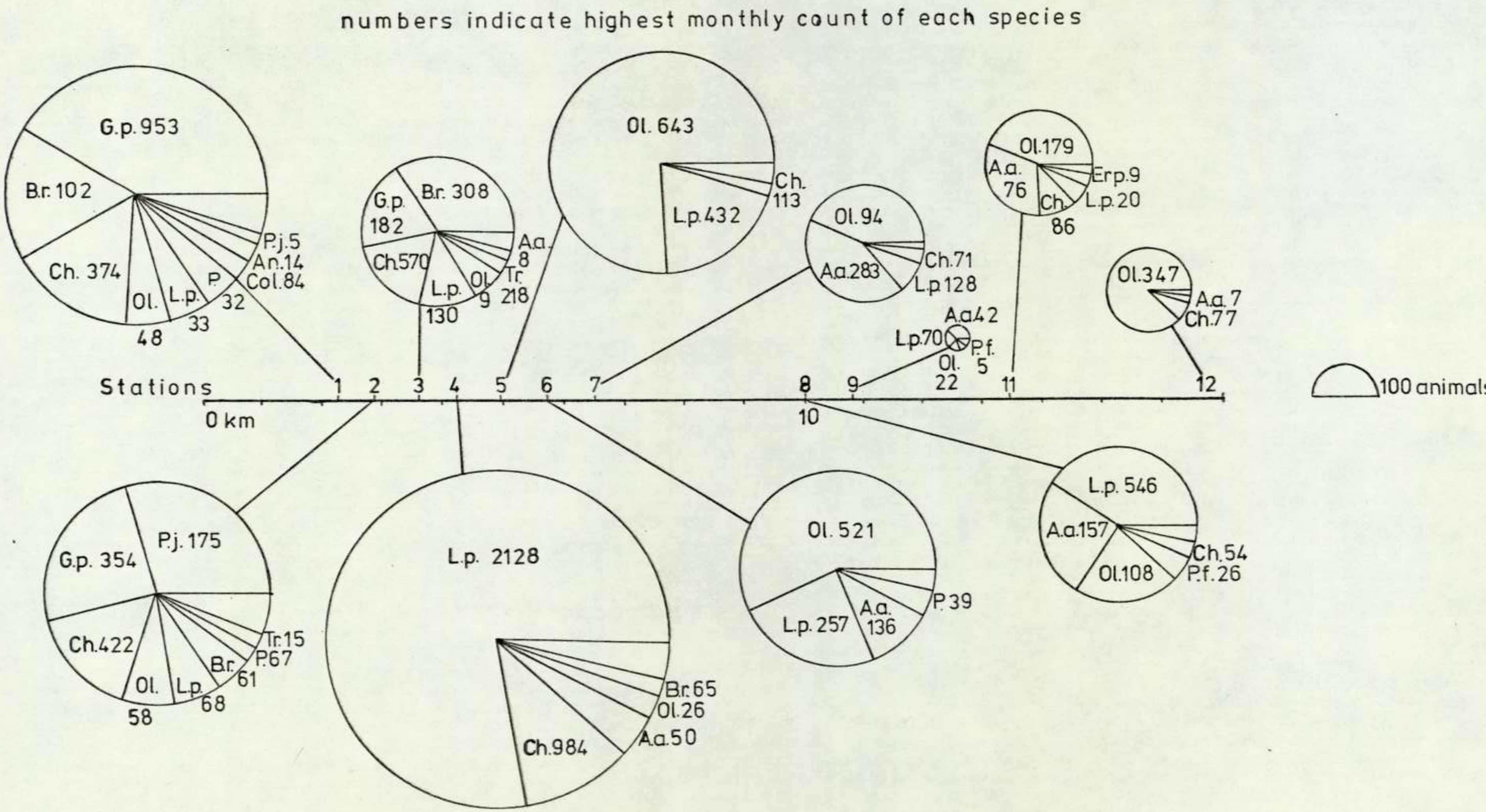

Fig.4.7. Diagram showing mean percentage composition of the macroinvertebrate fauna in the River Stour 1967 -1968

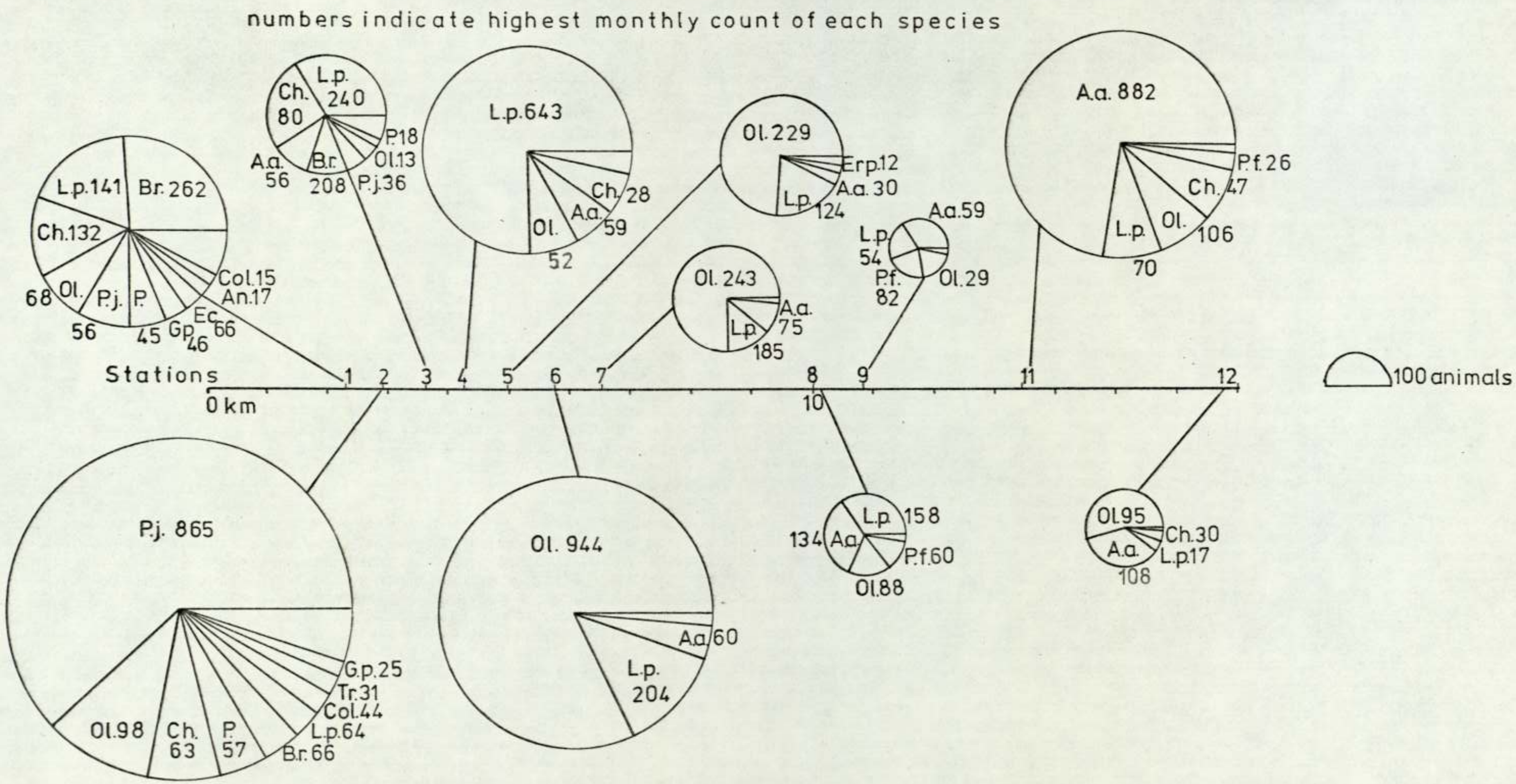

Fig.4.8. Diagram showing mean percentage composition of the macroinvertebrate fauna in the River Stour 1968–1969

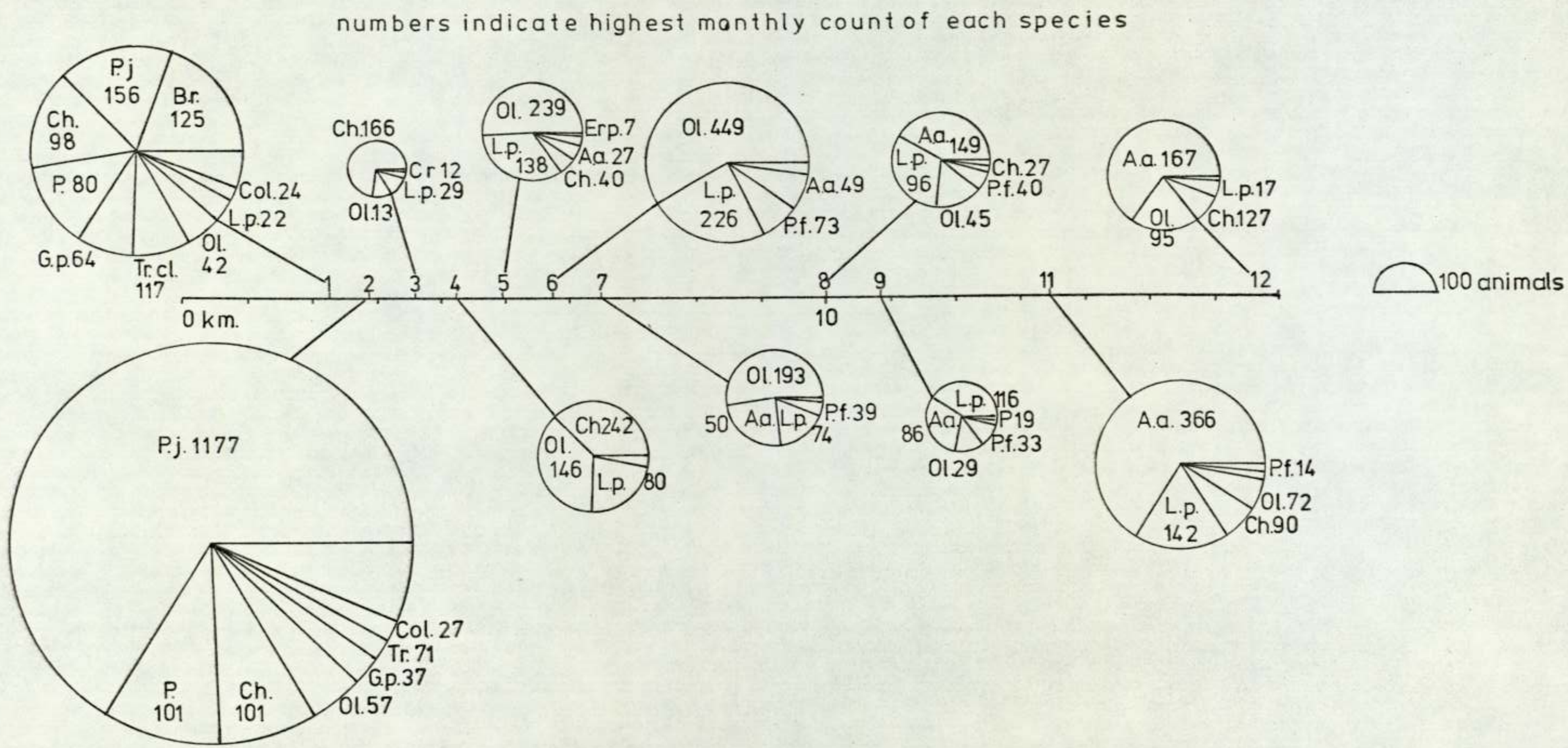

Fig.4.9. Diagram showing mean percentage composition of the macroinvertebrate fauna in the River Stour 1969 -1970

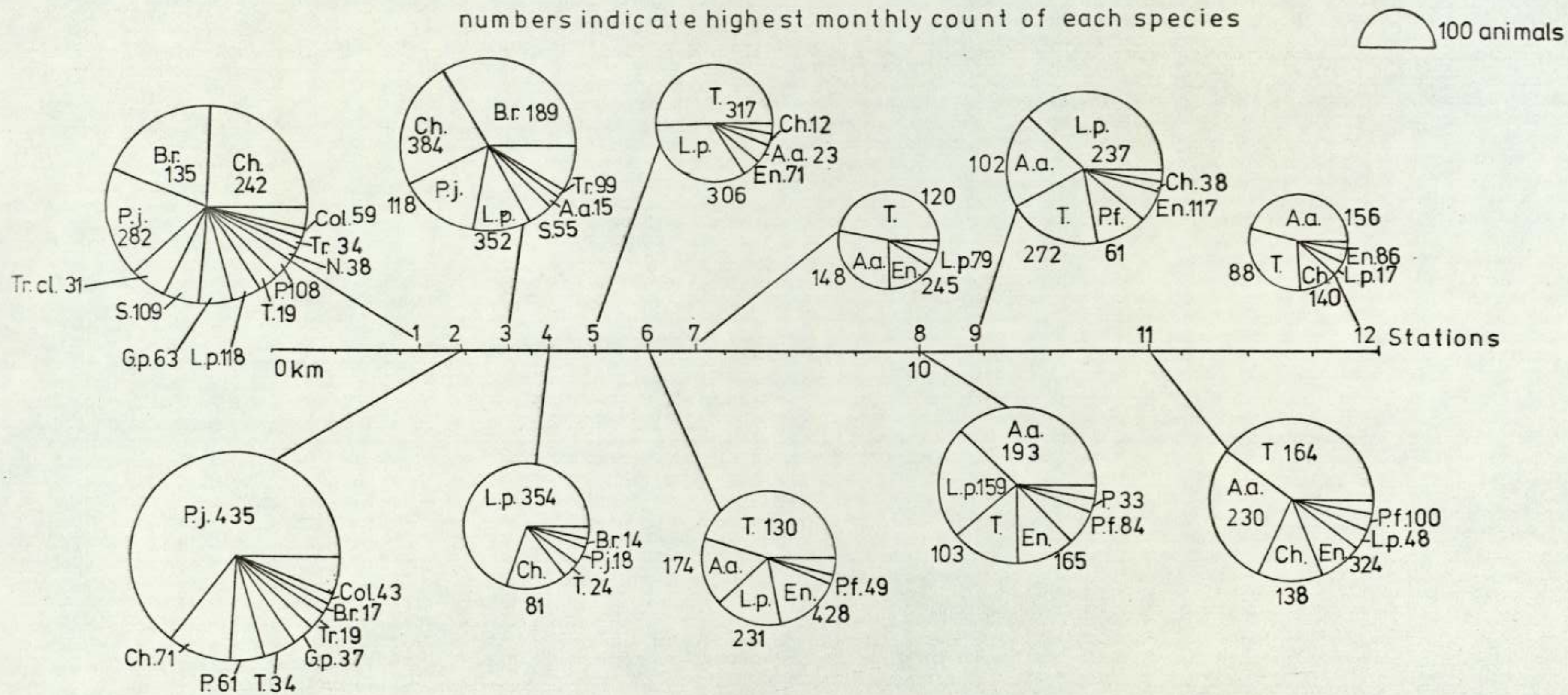

Fig.4.10 Diagram showing mean percentage composition of the macroinvertebrate fauna in the River Stour 1970-1971

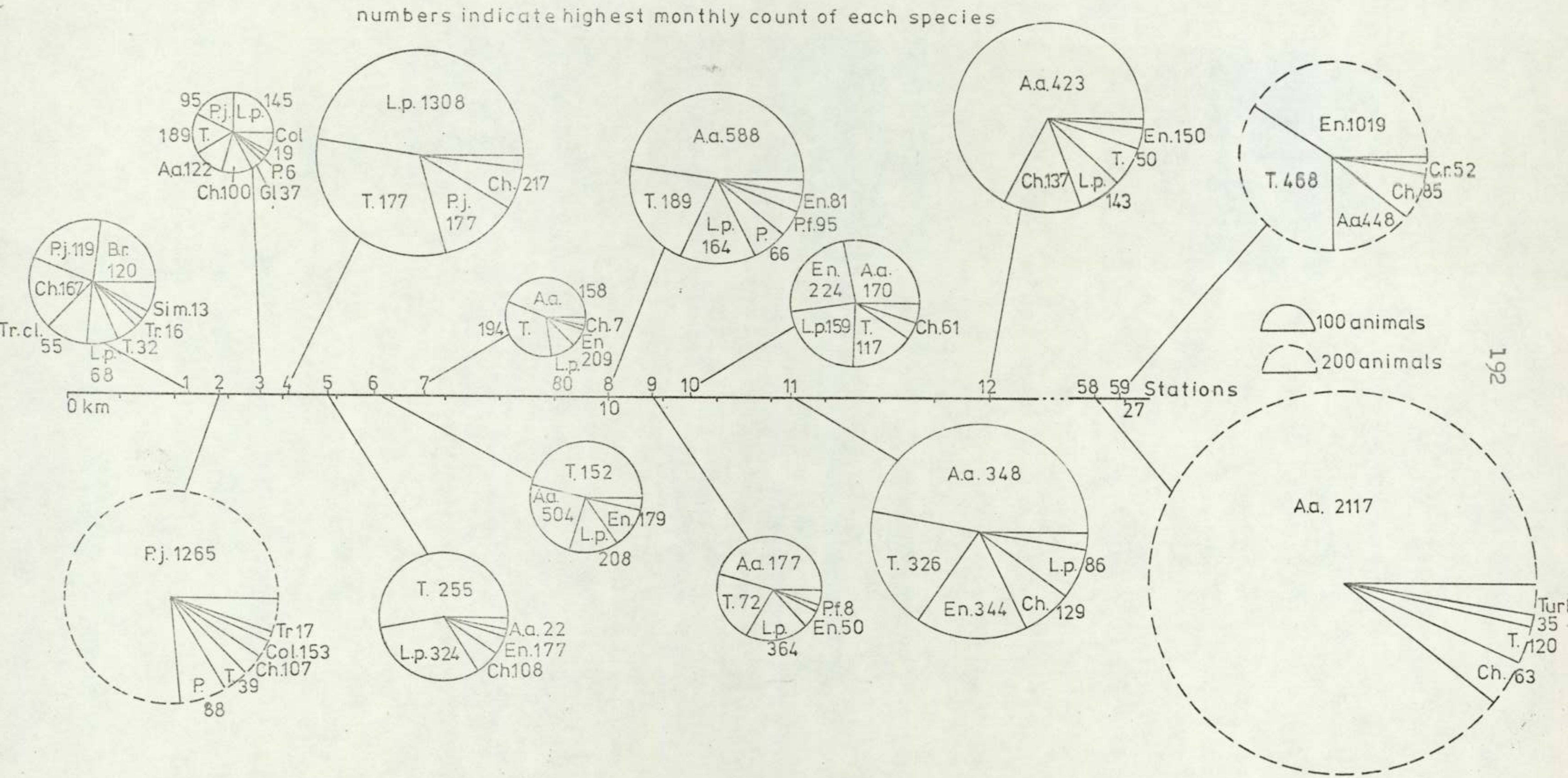

Fig.4.11. Diagram showing mean percentage composition of the macroinvertebrate fauna in the River Stour 1971-1972

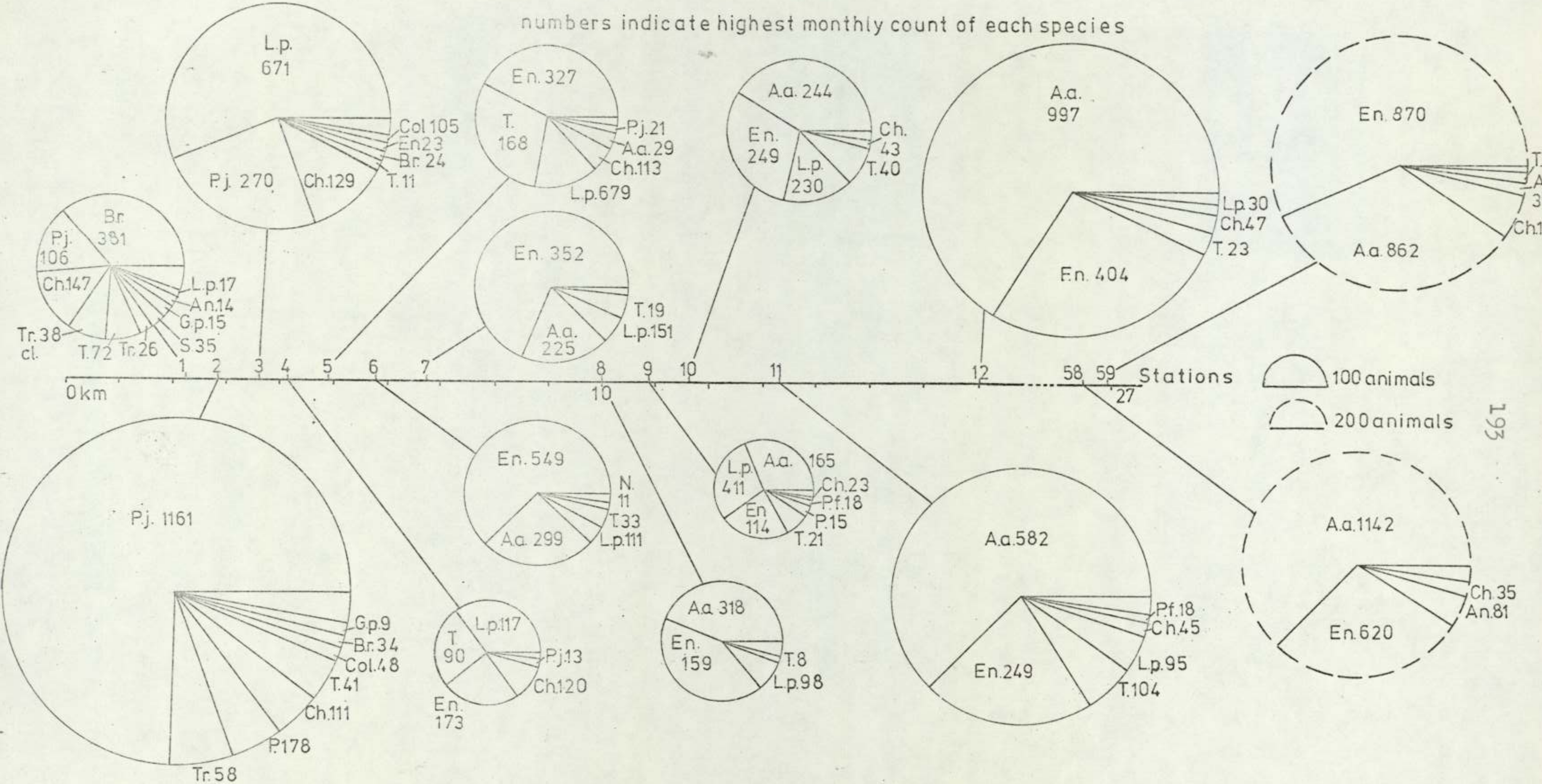

Fig. 4.12. Diagram showing mean percentage composition of the macroinvertebrate fauna in the River Stour 1972-1973

sewer upstream eliminated any clean-water fauna present by February 1969. After remedial work on this sewer, mayfly nymphs and caddis larvae returned by the following two months. By May, however, conditions had deteriorated again because discharges of silt-laden water from new sewer excavations on the gas works site upstream had coated the substratum, including the benthic algae, thus rendering the bed inhospitable to many species, including Asellus, Baetis, caddis and Limnaea. Butcher (1948) found that many species of algae, including some diatoms, were intolerant to silt. Hynes (1960) concluded that stoneflies, mayflies and caddisflies were more adversely affected by silt than other groups and that worms and chironomids survive. No sample was taken in August when the river was laden with crude sewage. Over the ensuing months there was a noticeable increase, not entirely seasonal, in the chironomid population, including C. riparius, but an initially surprising lack of worms. It is possible that the silt-laden and, at times, organically-polluted water was of advantage to the midges, though the comparatively small numbers (Fig. 4.9., page 190) suggest that much of the suspended solids was inorganic in nature. Tubificids were not common before this time, possibly because of the adverse effects of creosote seeping from the gas works site, and further inorganic pollution would have been of little benefit. Cladophora also disappeared and did not re-appear until July 1970 after the cessation in April of the silt-laden discharge. Baetis rhodani was also found again in July

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and became dominant by October when Gammarus and Asellus had also re-appeared. Baetis became increasingly dominant over the following months until its seasonal emergence in June 1971. Gammarus, however, did not thrive and was not found after May 1971. Chironomids, molluscs and Asellus became increasingly common, but Baetis did not re-appear possibly because of a newly installed surface-water sewer upstream, discharging polluting liquor (Fig. 4.10, page 191).

A temporary abundance of tubificids in June 1972 may have been caused by increased organic matter being deposited following blockages upstream. This was followed by a peak in the chironomid population in the following month and then by a seasonal increase in Limnaea pereger in August. This species remained dominant until the end of the study period (Fig. 4.12, page 193). A surcharging foul sewer during the period March to May 1973 seemed to have little effect on the composition of the community but there was a reduction in numbers.

Station 4 (River Stour, downstream of Halesowen).

Limnaea pereger dominated the fauna at station 4 during the first two years (Figs. 4.7. and 4.8., pages 188 & 189), but in June 1969 there was a drastic reduction in its population (Appendix Tables 19 & 20). The discharge of silt-laden water at station 3, described above, had by June affected the macroinvertebrate community at station 4. Usually Limnaea was common throughout the year and showed a peak of abundance in August and September, but in 1969, despite the seasonal increase, the population was comparatively very much reduced (Appendix Tables 20 & 21). This was almost certainly caused by the deposition of silt on the benthic algae which form part of the diet of Limnaea. At the same time there was an increase in the chironomid and oligochaete populations due to the increasingly silty conditions. This condition continued until April 1970, though chironomids and oligochaetes continued to dominate until July, when the improved conditions enabled the seasonal increase in Limnaea pereger to proceed as usual (Fig. 4.9, page 190).

Limnaea remained dominant until December 1971 (Figs. 4.10 and 4.11, pages 191 & 192), when the gradual increase in deposition of silt brought about by dredging, re-alignment and culverting of the river upstream resulted in a decrease in Limnaea and in Potamopyrgus jenkinsi, which had become common in July, and an increase in tubificids at station 4. This change was gradual but by June 1972 tubificids had become dominant. The population was not large, however, probably because of a lack of organic matter. By the following month enchytraeids had increased and in September chironomids. The seasonal increase of Limnaea was again subdued but it increased in importance until March 1973, when the surcharging foul sewer upstream of station 3 brought about a decrease in Limnaea and an increase in tubificids and in April enchytraeids (Fig. 4.12, page 193).

Stations 5, 6, and 7 (River Stour, Furnace Hill to Bellevale).

The three stations 5, 6 and 7, between Furnace Hill, Halesowen and Bellevale, Cradley, may be considered together since they were all affected to a greater or lesser extent by the pollution load introduced by the Coombeswood tributary, which enters the river just upstream of station 5. Station 7 was also affected to some extent by the foul sewer washout at Hayseech, half a mile upstream (Appendix Tables 25 to 42).

The riffle community was found to be restricted at station 5 from the time of the first survey. The community was usually dominated by tubificid worms or seasonally (August to October) by Limnaea pereger (Fig. 4.7, page 188). This situation was brought about by an overburdened foul-sewer surcharging into the Coombeswood tributary. Asellus was poorly represented here, but downstream, at station 6, where the effects of pollution were diminished, it was more common and even more so at station 7, where it was often dominant. In January 1968, greater flows of silt-laden, organically-rich water from Coombeswood induced an even greater dominance by tubificids at stations 5 and 6, but this dominance was not apparent at station 7 until March. During this month sewage fungus appeared at station 5, but had gone by the following month. No improvement was apparent until July at station 7 when Asellus became more common, but it was September before any changes occurred at stations 5 and 6, and these were due to the seasonal increase in the Limnaea population. Nevertheless, Limnaea remained co-dominant with tubificids until

January 1969, though at station 6 it was less successful, possibly because of the unstable nature of the bed (Fig. 4.8, page 189).

Following the repair of the surcharging foul-sewer in October 1969, there was a marked improvement at all three stations by November, when tubificids had either been reduced in number (stations 5 and 7) or lost (station 6). This improvement was short-lived, however, and by February and March tubificids were again dominant at all three stations. Further remedial work on the sewer brought about a slight improvement in June 1970, when tubificids were largely replaced by enchytraeids and Limnaea. The upper part of the Coombeswood tributary was culverted where it passed under the municipal refuse tip, which had been sited in this valley. In November, polluting liquor, which had probably been leeching to the watercourse for some time, increased in volume considerably. Consequently, there was a deterioration in the quality of this tributary, the effect of which was a considerable increase in the relative proportion of tubificids, more so at station 5 but also at stations 6 and 7. Sewage fungus was found at station 5 in January 1971, together with very few animals (11 tubificids), and was evident until May, when a decrease of the discharge from the tip brought about better conditions enabling the enchytraeid population to increase considerably, especially further downstream at stations 6 and 7 (Fig. 4.10., page 191). Further improvement enabled Asellus to increase at stations 6 and 7 and the seasonal increase of Limnaea pereger in August was evident at all three stations.

A reversal of this trend occurred in December 1971, when increasing numbers of tubificids and decreasing numbers of Asellus and Limnaea along this stretch indicated worsening conditions. By January 1972, sewage fungus had re-appeared and extended well downstream of station 7. Improvements were noticeable at station 7 in May with the increasing importance in the community of Asellus (Fig. 4.11, page 192), but it was July before any improvement progressed upstream to stations 5 and 6, when tubificids were replaced by enchytraeids. Asellus became more common at station 6, but was unable to enlarge its population at station 5. In October, there was a deterioration in conditions at stations 5 and 7, where tubificids (at 5) and enchytraeids (at 7) had increased and Asellus had decreased, but the reverse occurred at station 6. This was thought to be brought about by increased flows scouring coarse, polluting sediments from the Coombeswood tributary to station 5 and increased volumes of polluting liquid from the wash-out at Hayseech affecting station 7. By December 1972, increases in the population of tubificids at station 5 and enchytraeids at stations 6 and 7 marked the increased pollution from the tip (Fig. 4.12., page 193). There was also a return of sewage fungus to all these stations, which remained at station 7 until Feburary 1973, at station 6 until March and was still present at station 5 at the end of the study in June.

Stations 8 to 10 (River Stour, Bower Lane to Freehold S.T.W.).

There was a strong resemblance between the communities found at stations 8, 9 and 10. The fauna comprised mostly Asellus aquaticus, Limnaea pereger, tubificids, enchytraeids and Physa fontinalis (Appendix Tables 43 to 56). The seasonal increase in Limnaea pereger was usually in September, though large numbers were sometimes found in other months also. Usually the number of animals found was less at station 9 (Fig. 4.7., page 188) than at the other two stations, possibly because of the less stable substratum, though the adverse effect of discharges of toxic metals to Salt Brook and to the Bromley Street culvert, both of which join the river between stations 8 and 9, cannot be disregarded. High concentrations of zinc (28.5 mg/l.) were found in spot samples in August 1967. Table 4.3. which shows the maximum and mean results of zinc analysis for the period from March 1970 to June 1973, on spot samples taken at three month intervals, indicates a considerable increase in the zinc content of the river water from station 8 downstream. Since these results were based upon spot samples, it is possible that these do not represent the maximum concentrations to be found in the river, though of course the composition of the benthic community would reflect any higher concentrations. Upstream of station 8, the maximum known source of zinc was Old Hill Brook, the first station downstream of which was station 22 on Mousesweet Brook.

Table 4.3. Concentration (mg/l) of Iron, Copper and Zinc found in stream water

Station	Iron		Copper		Zinc	
	Max.	Mean	Max.	Mean	Max.	Mean
1.	4.6	0.9	0.1	0.02	0.06	<0.01
2.	5.0	1.1	0.1	0.02	0.1	0.01
3.	1.4	0.3	0.15	0.02	0.2	<0.01
4.	0.5	0.1	0.1	0.02	0.08	0.01
5.	3.0	1.6	0.15	0.02	0.1	0.04
6.	1.5	0.5	0.05	<0.01	0.05	0.01
7.	2.0	0.5	0.5	0.06	0.2	0.02
8.	4.0	1.0	0.1	<0.01	0.4	0.1
9.	3.0	0.8	0.1	0.02	0.42	0.2
10.	3.0	0.9	0.1	0.03	0.35	0.18
11.	4.0	1.1	0.2	0.06	0.6	0.26
12.	3.4	1.0	0.3	0.07	0.4	0.17
58.	1.2	0.7	0.2	0.06	0.2	0.10
59.	3.8	0.4	0.1	0.01	0.3	0.11
13.	4.0	0.6	0.1	0.02	0.1	0.01
14.	2.0	0.5	0.05	0.01	0.06	0.01
15.	0.6	0.2	0.1	0.02	0.3	0.03
16.	3.8	0.6	0.2	0.03	0.1	0.02
17.	2.0	0.4	0.2	0.02	0.06	0.01
18.	1.1	0.3	0.05	0.01	0.06	0.02
20.	7.0	0.8	0.2	0.02	0.32	0.14
21.	7.4	1.2	0.2	0.03	0.46	0.17
22.	9.0	1.4	0.4	0.05	1.66	0.80
24.	13.0	2.3	0.2	0.02	1.00	0.29
23.	2.0	0.4	0.2	0.04	0.1	0.06
51.	3.0	0.7	0.2	0.02	0.29	0.05
52.	0.4	0.07	0.1	0.01	0.1	0.02

Table 4.3. cont.

Station	Iron		Copper		Zinc	
	Max.	Mean	Max.	Mean	Max.	Mean
25.	9.5	1.36	0.2	0.03	0.12	0.03
26.	5.5	0.9	0.6	0.05	0.2	0.04
27.	10.0	3.9	0.2	0.05	0.3	0.12
28.	3.0	0.9	0.2	0.03	0.2	0.05
55.	3.0	0.5	0.2	0.02	0.12	0.03
56.	3.6	0.6	0.1	0.02	0.04	0.01
29.	2.4	0.3	0	0	0.1	0.01
31.	1.0	0.1	0.2	0.04	0.1	0.01
49.	5.0	1.4	0.2	0.07	0.06	0.02
54.	5.0	1.0	0.3	0.04	0.09	0.04
32.	1.4	0.3	0.1	0.03	0.2	0.04
33.	0.5	0.1	0.2	0.03	0.24	0.05
34.	1.0	0.2	0.1	0.02	0.1	0.02
35.	2.0	0.6	0.3	0.06	0.2	0.04
50.	7.2	1.9	0.15	0.04	0.1	0.06
36.	2.0	0.5	0.1	0.02	0.1	0.02
37.	4.0	0.5	0.25	0.04	0.1	0.03
38.	1.4	0.3	0.2	0.03	0.1	0.02

Comparatively little work has been done on the effects of toxic metals on macroinvertebrates (see section 1.5). It would seem that tubificids are fairly resistant to zinc and lead (Whitley, 1968) and experiments done during this study (see 5.2) showed that Asellus was fairly resistant to zinc, but Limnaea was not. The only occasion when tubificids or enchytraeids and Asellus were common and Limnaea rare at stations 8 and 9 was in October 1971 and for all three stations from October/November 1972 until the end of the survey. The mean of three samples taken for zinc analysis in December 1972, March 1973 and June 1973 was 0.16 mg/l at station 8 and 0.23 mg/l at stations 9 and 10. Maximum concentrations of zinc were found in March 1972 (0.4 mg/l) at station 8, March 1971 (0.42 mg/l) at station 9 and June 1973 (0.35 mg/l) at station 10. On all these occasions there were small populations of Limnaea and larger populations of either Asellus or tubificids. At the present state of our knowledge, however, to suggest that these changes are definitely because of the effect of zinc is debatable.

Stations 11 and 12 (River Stour, Stambermill and Wordsley).

The possible influence of zinc was even more evident further downstream at station 11, about one and a half kilometres downstream of the discharges from Freehold and Caledonia Sewage Treatment Works. Table 4.3. (page 201) shows that the highest concentrations of zinc were found at station 11 and Tables 4.4. and 4.5. (pages 204 & 205) show the concentrations of zinc

Date	BOD			NH_3			$NO_2 + NO_3$			Total Metals	Zinc
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Av.	Av.
8/67-3/68	18	8	14	26			5.3	4.2	4.7	-	-
4/68-3/69	28	5	16	21	16	18	20	2.3	7.1	-	-
4/69-3/70	13	4	7	29	12	22	3.5	1.0	1.7	0.48	0.21
4/70-3/71	11	4	8	32	17	25	5.4	1.0	2.0	0.45	0.30
4/71-3/72	18	8	13	31	18	27	5.2	1.0	2.2	0.64	0.34
4/72-3/73	14	5	8	31	21	27	4.2	1.2	2.2	0.74	0.31

All figures in mg/l.

Table 4.4. Chemical Analyses of Final Effluent from Freehold S.T.W. to the River Stour

Date	BOD			NH_3			$NO_2 + NO_3$			Total	Zinc
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Metals Av.	Av.
8/67-3/68	16	10	13	-	-	-	34	23	28	-	-
4/68-3/69	14	8	10	0.8	0.7	0.7	53	10	33	-	-
4/69-3/70	14	6	10	2	0.6	1.4	35	18	23	0.56	0.35
4/70-3/71	16	6	10	4	0.5	1.6	24	15	20	0.52	0.33
4/71-3/72	19	8	13	4	0.3	1.7	25	13	20	0.89	0.48
4/72-3/73	20	9	12	4	0.5	1.9	27	18	22	1.43	0.74

All figures in mg/l.

Table 4.5. Chemical Analysis of Final Effluent from Caledonia S.T.W. to the River Stour

found in the final effluents discharged to the River Stour from the Freehold and Caledonia Works. Flow to Freehold Works, an activated sludge plant, commenced in August 1967, relieving some of the loading to Caledonia Works, which operates with double filtration and to Whittington Farm. The waste which used to flow partly to Whittington Farm (5 m.g.d.) and partly to Caledonia Works (1 m.g.d. but often up to 2 m.g.d.) was divided into two equal portions, 3 m.g.d. going to Freehold Works and the remainder to Caledonia Works and Whittington Farm. However, the concentrations of zinc and total metals was consistently higher in the effluent from Caledonia Works (Tables 4.4 and 4.5). Between the discharge from Caledonia Works and station 11, the major discharges to the river included a surface-water channel persistently polluted with copper, nickel and zinc from a plating firm, the combined waters of Ludgbridge Brook and Shephards Brook, and an unnamed brook from Upper Swinford. Samples taken of the discharge from the plating firm to the channel contained as much as 255 mg/l of zinc, 350 mg/l of copper and 112 mg/l of nickel, a large proportion of these metals being in suspension. After June 1969, discharges from the plating firm were diverted to the foul sewer. Samples of water taken in August 1967 from station 11 and from station 12, about 3 km. downstream, were found to contain 1.1 mg/l and 2.4 mg/l of zinc respectively. During this month, small populations of tubificids were dominant at both stations and continued to be so until the end of the year at station 11, but until September 1968 at station 12 (Fig. 4.7., page 188). Numerous discharges from the industrial part of Stourbridge entered the river between stations 11 and 12 besides the water of known polluted streams such as Wordsley Brook.

It is possible that the better purification achieved by the operation of Freehold Works resulted in some reduction of the zinc concentrations. Unfortunately, no figures are available for metal analysis of works effluents prior to 1970, so the direct effect of the Freehold works on the zinc concentration in the river cannot be assessed. It would appear, however, that some three months after the start of operation of Freehold works, there was a marked reduction in the tubificid population at station 11 (Appendix Table 57) unmatched by a similar change at station 12. Whether this was due to a lower organic loading in the river or also because of lower zinc values cannot be stated with certainty. Sewage fungus, which had been found at the beginning of the survey at station 11, was no longer apparent after a couple of months.

Asellus became dominant after this initial period and remained so far most of the time until December 1970, when an increase in the proportion of tubificids coincided with high zinc values in the river at stations 11 and 12 (Appendix Tables 60 & 66). Small numbers of tubificids continued to dominate the communities at these two stations until May 1971, when enchytraeids became more numerous. Apart from increases in the chironomid population there was no trend towards better conditions until September 1971, when Asellus and Limnaea increased in numbers. Limnaea usually showed a seasonal increase in August or September, but it was usually subdued and short-lived. Asellus continued to dominate the fauna at both stations for the rest of the survey period (Figs. 4.11., 4.12, pages 192 & 193), apart from a few isolated months. The spot samples taken at the two stations for metal analysis showed a general decline in zinc concentration during this last period.

The effluent from Freehold works, although having low suspended solids and BOD values, generally had high ammonia values. Little or no work seems to have been done on the effects of ammonia on benthic organisms, but its possible effects on the benthic fauna of the River Stour cannot be discounted. Information from the former Severn River Authority showed, that the ammonia concentration in the river rose considerably just downstream of the Freehold discharge and did not fall until some distance downstream. There was little or no difference in the benthic fauna upstream and downstream of the Freehold discharge, so the effects of ammonia could not be assessed. Hynes (1960) stated that Chironomus riparius and C. dorsalis could withstand fairly high concentrations of ammonia, but neither of these species was found at station 10. There seems to be no information available on the tolerance to ammonia by the common species found at station 10. Hawkes (1963a) found in

Month	BOD				NH_3				$NO_2 + NO_3$			
1969	u/sF	d/sF	u/sC	d/sC	u/sF	d/sF	u/sC	d/sC	u/sF	d/sF	u/sC	d/sC
Feb.	6.0	9.8	-	9.3	3.2	27.5	-	13.7	7.6	7.8	-	10.9
Mar.	-	-	-	-	3.2	-	3.2	3.0	2.4	2.5	-	2.4
Apr.	-	-	-	-	0.6	8.0	6.8	5.9	5.4	3.9	3.5	18.4
May	1.2	0.8	2.0	1.6	12.0	-	-	-	1.2	1.2	1.2	1.2
June	-	-	-	-	0.6	5.8	4.5	3.8	5.8	5.2	5.2	-
July*	1.7	3.0	5.0	5.7	0.4	10.6	6.5	4.7	4.0	NIL	3.4	4.7
Aug.*	-	-	1.0	3.7	1.2	7.1	2.2	2.2	1.3	1.1	2.3	2.5
Sept.	-	-	6.0	8.5	-	-	5.3	4.1	-	-	2.5	5.0
Oct.*	0.2	3.7	5.0	9.2	0.9	6.5	6.5	5.0	5.4	1.1	4.1	15.0
Nov.	4.7	13.7	-	-	1.4	10.6	-	-	1.3	1.2	-	-
Dec.*	3.0	3.6	6.6	5.7	0.9	10.0	10.0	8.9	0.2	0.2	2.8	9.0
1970												
Jan.*	4.5	5.2	3.9	7.5	0.8	5.0	2.0	2.0	6.8	6.1	5.7	8.0
Feb.	4.3	3.6	10.5	10.1	1.5	6.2	7.7	7.1	3.2	2.1	5.5	6.5
Mar.	-	-	-	-	-	-	3.5	3.5	-	-	4.7	5.7
Apr.*	2.2	2.2	2.7	4.2	1.5	6.2	4.7	3.5	6.6	4.1	5.0	6.8
May	2.5	3.3	-	-	0.4	5.6	-	-	4.9	4.0	-	-
June*	3.2	5.0	5.4	8.1	0.9	18.8	6.5	5.0	5.0	2.1	4.0	7.9
July*	8.1	5.4	11.0	5.0	1.2	5.3	8.3	6.5	5.0	3.9	3.2	5.9
Aug.*	0.8	5.8	7.3	5.5	0.3	8.0	5.0	4.1	5.0	4.6	4.4	7.3
Sept.*	0.6	1.2	1.5	5.9	0.9	7.4	9.4	9.4	-	-	3.7	9.3
Oct.*	5.0	4.0	6.3	9.5	0.6	4.4	4.1	3.2	2.9	2.9	3.3	7.1
Nov.	-	-	3.5	5.0	-	-	3.2	3.0	-	-	5.9	7.1
Dec.*	4.0	2.0	-	-	0.7	3.5	10.3	9.4	7.4	7.0	3.7	7.2

F - Freehold S.T.W. C - Caledonia S.T.W.

* Samples near Freehold and near Caledonia not taken on the same day

all figures in mg/l.

Table 4.6. Chemical Analysis of River Water: River Stour upstream and downstream of discharges from Freehold and Caledonia S.T.W.

Month	BOD				NH_3				$NO_2 + NO_3$			
1971	u/sF	d/sF	u/sC	d/sC	u/sF	d/sF	u/sC	d/sC	u/sF	d/sF	u/sC	d/sC
Jan.	3.3	0.4	-	-	4.4	17.2	-	-	7.4	7.0	-	-
Feb.*	3.2	6.9	2.0	2.1	4.4	8.9	-	-	5.9	4.1	5.4	6.6
Mar.	0.1	4.0	3.3	3.5	0.6	10.3	7.4	6.5	3.7	3.2	3.1	5.5
Apr.	-	-	-	-	0.8	8.6	-	-	7.5	5.4	-	-
May	-	-	5.1	8.3	-	-	6.8	5.6	3.7	3.9	3.1	5.1
June*	2.6	6.7	4.5	7.4	-	-	-	-	6.3	5.1	3.1	9.9
July	-	-	-	-	-	-	3.8	3.0	-	-	3.4	6.2
Aug.	1.7	3.3	-	-	Tr.	5.0	-	-	Tr.	0.1	-	-
Sept.	6.0	6.2	-	-	6.5	9.7	-	-	5.0	5.1	-	-
Oct.*	0.4	1.3	4.5	3.2	0.6	1.5	10.0	7.4	6.3	5.7	3.1	9.2
Nov.	1.5	3.0	1.8	4.1	1.5	8.3	5.3	4.4	3.0	2.4	4.7	8.9
Dec.	-	-	4.5	5.3	-	-	9.8	7.8	-	-	2.4	7.8
1972												
Jan.	-	-	4.4	5.0	-	-	1.2	0.3	-	-	-	-
Feb.	-	-	3.3	4.5	-	-	8.0	5.3	-	-	5.9	9.3

* Samples near Freehold and near Caledonia not taken on same day.

F - Freehold. C - Caledonia

all figures in mg/l.

Table 4.6. Chemical Analysis of River Water: River Stour upstream and downstream of discharges from Freehold and Caledonia S.T.W.

the River Cole, that <u>Limnaea peregar</u> was adversely affected where ammonia concentrations increased downstream of a discharge from an overloaded sewage works, but chironomids and tubificids were little affected.

<u>Stations 58 and 59 (River Stour, u/s and d/s discharge from Roundhill S.T.W.).</u>

The results from samples taken at station 58 and 59 (Appendix Tables 69 to 72), situated respectively upstream and downstream of the discharge from Roundhill Farm and after January 1972 Roundhill Sewage Treatment Works, show that at station 58 the macroinvertebrate community was restricted to some extent by pollution and was dominated, for much of the period studied, by <u>Asellus aquaticus</u>. (Figs. 4.11, 4.12, pages 192 & 193). At station 59, although <u>Asellus</u> was common and sometimes dominant, tubificid and enchytraeid worms were usually more abuhdant, especially in the earlier months (Fig. 4.11, page 192). Samples were first taken at these two stations in November 1971, some two months prior to the start of flow from the new Roundhill Sewage Treatment Works.

Table 4.7. (page 212) shows the results of chemical analysis on samples of effluent from Roundhill Farm from 1969 to 1972 and from Roundhill works for 1972 and 1973. These results indicate the polluting nature of the discharge from the Farm and the relative improvement of the final effluent from the works. Tables 3.10 and 3.11 (pages 141 & 142) give more detailed results from the works. It will be seen that by March 1972, there was some improvement in the BOD and ammonia loading of the

Date	BOD			NH_3			$NO_2 + NO_3$			Total Metals	Zinc
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Av.	Av.
4/69-3/70	136	9	50	29	16	23	4	1.3	2.8	0.48	0.23
4/70-3/71	137	27	60	36	17	25	7	3.3	4.7	0.43	0.19
4/71-1/72	202	37	82	40	16	25	6	1.4	3.6	0.98	0.50
Roundhill Farm											
1972	56	19	33	31	3.6	9.1	34	2.3	18	0.74	0.30
1973	39	14	21	13	1.3	5.8	30	6.6	18	0.94	0.30
Roundhill S.T.W.											

Table 4.7. Chemical Analysis of Final Effluent from Roundhill Farm and from Roundhill S.T.W. to the River Stour.

discharge and in the oxidised nitrogen content. Sewage fungus and Chironomus riparius found in the early months of the survey became reduced as conditions in the river at station 59 improved. According to Hynes (1960), as the concentration of organic matter becomes lower, sewage fungus becomes less and chironomids, especially C. riparius, begin to appear with the tubificidae. In February 1972, although there was an increase in the number of tubificids there was a comparatively greater increase in the Asellus population. There was another change in April, when tubificids and Asellus were considerably reduced in number and enchytraeid worms were increased. This community, dominated by enchytraeids, continued until the end of the year by which time Asellus had increased its population (Appendix Table 72). After this time, dominance was shared by enchytraeids and Asellus. (Fig. 4.12, page 193).

As described in section 2.3.2., the filters at Roundhill were subject to a number of breakdowns, especially during the first year. However, because of the differences in the times of breakdown and the times of river sampling and perhaps also because of the influence of pollution from upstream, distinct changes in the riffle populations could not be correlated with conditions at the works. Moreover, Table 3.10. (page 141) showed that by September the effluent was well-nitrified despite the breakdowns. After November 1972, the correlation between the community at station 58 with that at station 59 was closer, suggesting that by this time the effluent from

Roundhill was having a less deleterious impact on the fauna at station 59 and that the general conditions prevailing in the river upstream of the effluent were having a comparatively greater influence. Chironomid larvae and Ancylus fluviatilus started to appear in considerable numbers and a few turbellarians (Dendrocoelum lacteum, Polycelis felina) and Gammarus pulex were also found. Although Asellus had become more frequently found, station 59 could not be described as being in an "Asellus zone" (Hynes 1960) unlike station 58, where Asellus was usually dominant.

Stations 13, 14 and 15 (Illey Brook).

Illey Brook drains farmland in its upper reaches before receiving the effluent and land irrigation drainage from Hunnington Sewage Treatment Works (until December 1970) and passing through a residential and partially industrialised part of Halesowen. The brook was found to support a varied, clean-water fauna for most of the period at station 13, except June 1968, when there was an increase in tubificids (Appendix Tables 73 & 74). Large populations of chironomids were usually found in June, so it is possible that a discharge of some specific pesticide or organic farm-waste had been washed into the brook from farmland. The effluent from Hunnington Sewage Treatment Works was unsatisfactory organically since growths of sewage fungus downstream were extensive. Tubificids, enchytraeids, chironomids and sometimes (December 1968, December 1969, March 1970) Chironomus riparius dominated the fauna when the bed was covered with sewage fungus, but Gammarus and Baetis rhodani were usually present and sometimes Ecdyonurid nymphs and caddis larvae (Limnephilidae). Where sewage fungus was growing in shallow, turbulent water, Hynes (1960) found that naid worms were thriving, but that Gammarus and mayflies, although sometimes present, did not breed satisfactorily.

The Hunnington works was closed down at the beginning of 1971, but increased silty and sandy conditions at station 14 (Appendix Table 76) postponed any marked improvement until June, when Baetis rhodani nymphs became common. During subsequent sampling a clean-water fauna gradually became more evident with increases in mayflies, caddisflies and stoneflies. The community was rarely large, however, probably because of the predominantly sandy nature of the substratum. According to Hynes (1960) Ephemera spp., Caenis spp. and Tanytarsus spp. are often to be found in coarse silt. Ephemera danica was found at station 14. Nuttall (1972) found that where sand had been deposited Baetis rhodani, Rhithrogena semicolorata and Tubificidae were abundant.

The effect of the works effluent was less pronounced about half a kilometre further downstream at station 15 (Appendix Tables 77 & 78), though chironomid larvae were usually dominant until June 1971 and sewage fungus was apparent until December 1969. Part of the reason for this dominance by chironomids and, in June 1970, by tubificids was the discharge of silt-laden water from the sewer construction during late 1969 and early 1970, and also polluting discharges from a surface water sewer about a quarter of a kilometre upstream at Manor Lane, Halesowen. This latter source was stopped in early 1972 and by March the fauna had become dominated by Baetis rhodani. This dominance was short-lived, however, because increasing accumulation of rubbish slowed down the flow, leading to the establishment of a fauna favoured by these conditions.

Stations 16, 17 and 18 (Lutley Gutter)

The substratum at the Lutley Gutter stations comprised, for most of the period, stones embedded in sand. When flows were slack there was a greater preponderance of sand and conversely when flows were greater there was less sand present. The upper two stations, 16 and 17, (Appendix Tables 79 to 82) were dominated for the whole period by Gammarus and sometimes by Baetis rhodani nymphs. Weeds were rarely found at either station, nor was either station found to be subject to pollution. The reduced number of species at these two stations is not regarded as a consequence of any undetected source of pollution, but rather as a reflection of a rather uniform and inhospitable substratum. Station 18 (Appendix Tables 83 & 84), which was often more silty, supported fluctuating growths of Cladophora. Wrong connections to a surface-water sewer discharging just downstream of station 17 and further wrong connections to a surface-water sewer about 100 m. upstream of station 18, were sources of pollution at various times. These were never serious enough to eliminate both Gammarus and Baetis, but there was a greater proportion of tubificids, enchytraeids or chironomids when these discharges were most prevalent. Potamopyrgus jenkinsi was often present in quite large numbers, but its presence and absence could not be correlated with times of greatest pollution. Station 18 could be said, therefore, to be subject to mild organic pollution, which although altering the relative sizes of the constituent populations of the benthic community never brought about the total elimination of the less tolerant species. Pentelow (in Butcher et al., 1937) and Hynes (1960) both found that downstream of a very mild organic pollution, there was very little change in the composition of the fauna, but there were changes in the abundance of different species. Mayflies (except Baetis rhodani), stoneflies, caddisflies and beetles were fewer in number and chironomids were greater in number downstream of the outfalls.

Stations 20, 21, 22 and 24 (Mousesweet Brook)

Discharges of toxic metals were the prime sources of pollution in Mousesweet Brook. This brook drains a mainly long-established industrial area primarily engaged in the metal-processing industries. Part of the upper stretches are culverted and receive discharges of zinc and copper. Between stations 20 and 21 a small tributary which received discharges of zinc and chrome joins the brook. Old Hill Brook, which is culverted along most of its length and received serious discharges of zinc, joins

Mousesweet Brook between stations 21 and 22. About a quarter of a kilometre upstream of station 24, the combined waters of Saltwells Brook and Black Brook join Mousesweet Brook. The effect of these metals discharges was to considerably reduce the number of species in the brook, especially at stations 21 and 22 (Appendix Tables 87 to 90). Table 4.3. (page 201) shows the concentration of zinc found in spot samples between March 1970 and June 1973.

The most tolerant benthic macroinvertebrates at station 20 were tubificid and enchytraeid worms, chironomid larvae and Limnaea pereger, though the latter was most successful when zinc values were generally low. Since conditions upstream were probably no better, it is probable that Limnaea did not migrate or drift downstream but re-invaded the brook from the adjacent marshland. The combined effect of chrome (maximum 1.1 mg/l., mean 0.3 mg/l.) and zinc, and possibly other undetected pollutants at station 21 was to reduce greatly the number of individuals found, especially worms and Limnaea, compared with station 20. After June 1972, when the amount of chrome and zinc reaching the brook had been markedly reduced, a greater population of Limnaea became established only to be reduced again at the end of the survey when increased discharges of chrome become apparent. Anderson (1946) found that chromate was toxic at concentrations below 1.0 mg/l. to Daphnia magna, but there seems to have been no studies on the effects of chromium compounds on other crustaceans nor on molluscs or insects.

Concentrations of chrome (maximum 0.7, mean 0.2 mg/l) were still found further downstream at station 22, but much higher concentrations of zinc (maximum 1.66, mean 0.8 mg/l) were probably the main factor affecting the benthic community. The main source of this zinc was found to be a sludge dump at a galvanizing firm. Asellus was never found here and Limnaea rarely. Chironomids were the most abundantly found group, but tubificids were comparatively rare. Even after the reduction of chrome in June 1972, the zinc concentration was sufficient to severely restrict the fauna.

Although fairly high concentrations of zinc (up to 1.0 mg/l measured) were found at station 24, cleaner water from Black Brook enabled Asellus to thrive here and to dominate the benthic fauna for most of the time. Limnaea pereger was more frequently and abundantly found and Physa fontinalis also occurred. The small numbers at station 24 were probably a reflection of the type of substratum, which comprised stones with patches of clay in places. Also, the mean current velocity was usually greater here. At stations 20, 21 and 22, Stigeoclonium sp. was the only plant found, but at station 24, Cladophora sp., Stigeoclonium sp. and Potamogeton pectinatus occurred.

Station 23 (Saltwells Brook)

The principal biotic feature of Saltwells Brook was the dominance throughout the period by Potamopyrgus jenkinsi (Appendix Tables 93 & 94). This snail was often present in very large numbers possibly because of the higher temperatures in this brook caused by the discharge of cooling water from the Round Oak Steelworks. Prior to December 1969, a discharge of domestic waste from a surface-water discharge just upstream of station 23 was polluting the brook. The fauna during this time comprised mainly P. jenkinsi, Asellus aquaticus, Pisidium sp. and tubificids. In December 1969 this polluting discharge was stopped, but there was no change in the dominance after this, P. jenkinsi remaining more abundant than any other species. Towards the end of the study, however, Gammarus became more abundant than Asellus, and cased caddis and beetles were more evident. The substratum usually supported a vigorous growth of Cladophora, Potamogeton pectinatus or Callitriche sp.

Stations 51 and 52 (Black Brook)

Saltwells Brook joins Black Brook within Saltwells Woods, an area of deciduous woodland. Black Brook rises south of Dudley and receives overflows from Dudley Canal. Station 51, upstream of the confluence with Saltwells Brook was established in a riffle downstream of a short culverted section which opened out onto bedrock. Until December 1970 (Appendix Tables 95 & 96) it was dominated by P. jenkinsi, though in smaller numbers than at station 23. A. aquaticus, L. pereger and Pisidium sp. were also found in substantial numbers at times. Towards the end of 1970 a start was made clearing a site upstream for an opencast coal-mine adjacent to the brook. This activity led to an increase in the amount of silt being carried in the water. By March 1971, no P. jenkinsi were found at all, but Aselius and tubificids had become more abundant. Naid worms were the dominant invertebrates found in June, but by September had disappeared, when tubificids had become dominant. During this time an intermittent discharge of domestic waste from a surface water sewer upstream was aggravating this condition. Chironomids, including C. riparius, were more common in December, Asellus had increased its number and tubificids had been reduced. A few Gammarus were also found.

P. jenkinsi did not return in even moderate numbers until June 1972, but by September, when the silt content of the substratum had been much reduced, it was co-dominant with tubificids and chironomids. Gammarus was also common during this month and became dominant by December, when tubificids had disappeared and chironomids were few. At the end of the survey period, however, increasingly silty conditions coincided with a return to dominance by tubificids, a reduction in the Gammarus population and the disappearance of Potamopyrgus.

At station 52, downstream of the confluence with Saltwells Brook (Appendix Tables 97 & 98), the benthic fauna was usually unaffected by the effects of the increased silt upstream, mostly because the bulk of the water downstream of the confluence is contributed by Saltwells Brook. P. jenkinsi was dominant almost throughout the period except in March 1971, when there was a considerable reduction in its population and in December 1971 and March 1972, when P. jenkinsi was completely absent upstream at station 51. Asellus became dominant at these times when Potamopyrgus was sparse, but was replaced by Gammarus during the last 12 months of the study. A much reduced community was found in March 1972 following disturbance to the bed when the brook course was straightened out, but by June the station had been re-colonized.

Station 25 (Ludgbridge Brook)

The substratum, at station 25 on Ludgbridge Brook, comprised smooth, rounded stones embedded in sand. This somewhat inhospitable habitat supported a fairly restricted community dominated throughout by Gammarus pulex (Appendix Tables 99 & 100). Nymphs of Baetis rhodani were common at times, but never dominant. Following a discharge, in June 1970, from a surcharging foul-sewer about half a kilometre upstream, chironomids became common and to a lesser extent tubificids, but following remedial work, these disappeared or became rare.

Stations 26 to 28 (Wordsley Brook)

Although the water at station 26 on Wordsley Brook was always shallow, there was a tendency for the sub-stratum to become predominantly silty when growths of Sium sp. downstream reduced the current velocity. The station was retained, however, as the only possible stretch that could be sampled between the culverted section beneath the Leys refuse tip at Brockmoor and the discharge from the steelworks of Richard Thomas and Baldwins Ltd. Station 27 was situated a few metres downstream of this discharge and station 28 about 1.5 km. downstream.

In the first month that the brook was surveyed (June 1967) no benthic macroinvertebrates were found at stations 26 and 27, and only three *Erpobdella* at station 28 (Appendix Tables 101, 103 & 105). The main sources of pollution were the refuse tip and the steel-works discharge. By June 1968, a number of species was found at station 26, including *Limnaea pereger*, *Asellus aquaticus* and chironomids. This improvement continued and by December *Gammarus* had appeared. No animals were found at station 27 until December 1968, when a few *Asellus* and *Erpobdella* occurred. Evidently the steel-works discharge contained considerable quantities of iron (Table 4.3., page 201), since iron deposits were always found on the brook bed downstream.

The culvert beneath the tip fractured in February 1969 and grossly polluting liquor, containing high concentrations of hydrogen sulphide, poured into the brook. No animals were found downstream of the culvert. A few tubificids were found at station 28 in June, but nothing in September. Invertebrates did not re-appear at station 26 until March 1970, following reculverting of the broken section, when a fairly large number of *C. riparius* larvae were found together with other chironomids, tubificids and *Asellus*. At station 27 benthic fauna re-appeared in the same month, but in fewer numbers and with tubificids dominant. As conditions improved at the two stations chironomids were largely replaced by *Asellus*, *L. pereger* and *Physa fontinalis*. A few *Gammarus* appeared and even an occasional cased caddis larva. The benthic fauna at station 27 often had a coating of iron deposits. A small, clean tributary upstream of station 28 introduced Gammarus but it was unable to thrive and compete successfully with Asellus.

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Stations 55, 56, 29 and 31 (Dawley Brook)

Dawley Brook flows through Kingswinford, which is mostly a residential area of Dudley, though there are three industrial estates which drain to the brook. One of these, Pensnett Trading Estate, was the source of persistent pollution, mostly by petroleum products, iron in solution and solids derived from concrete manufacture. About 0.25 km. downstream of the discharge from this estate there is a small lake into which a surface water sewer sometimes polluted with domestic waste discharged. Just upstream of the lake a small stream from Hams Lane Industrial Estate joins the brook; this stream was polluted with oil at times. Downstream of the lake, drainage from Dawley Brook Industrial Estate flowed to the brook.

Station 55, about 0.5 km. upstream of the discharge from Pensnett Trading Estate, was found to have a fauna dominated by Gammarus pulex (Appendix Table 107). Downstream of the discharge, at station 56, the bed was often covered by iron deposits and became quite silty or sandy at times. The fauna comprised only tubificid or enchytraeid worms for most of the period and these were usually few in number (Appendix Table 108). Supplementary inspection of the brook fauna showed, that Gammarus was present until just upstream of this polluting discharge.

Station 29 was established downstream of Dawley Brook Industrial Estate. At first, P. jenkinsi was the dominant species, but increasingly silty conditions, due to partial blockages downstream, resulted in a decrease of this species and an increase in the relative importance of tubificids (Appendix Tables 109 & 110). Other molluscs became more common also including L. pereger, Sphaerium sp. and Pisidium sp. However, P. jenkinsi gradually enlarged its population and dominated the community for most of the remaining period. The small lake upstream was thought to act as a natural settling basin for suspended solids from upstream, but these probably exerted a marked oxygen demand since the dissolved oxygen concentration at station 29 was always comparatively low. It is possible, of course, that even lower concentrations of dissolved oxygen occurred, but it is improbable that this was the cause of the absence of Asellus and other poorly-represented arthropods. A more likely reason could have been the lack of ease of colonization, due to pollution upstream and culverting downstream. Midges could colonize in the adult stage, but even these were few in number. A high wall adjacent to the station resulting in shading of the brook and possibly a paucity of benthic algae could have been another contributary cause of the poor arthropod fauna.

Station 31 was situated about one kilometre further downstream. P. jenkinsi was dominant here until June 1969, when it was reduced drastically and replaced by tubificids (Appendix Tables 111 & 112). This change was probably caused by increased pollution or by increasingly sandy and silty conditions, when part of the brook upstream was culverted through the site of a new housing estate. Tubificids and chironomids were favoured by this increased silt and dominated the community until September 1971, when there was a decrease in the amount of finer material. L. pereger and P. jenkinsi re-appeared in large numbers and the latter dominated the fauna until June 1973. Asellus, which was absent from station 29, was found in increasing numbers at station 31.

Stations 49, 54, 32 and 33 (Bob's Brook)

Bob's Brook rises in farmland south of Sedgley and flows southwards through a deciduous copse. Station 49 was within the copse and station 54 at the southern end of it. About 0.25 km. downstream, where a mostly culverted tributary joins the brook, was station 32. This tributary was often polluted by domestic waste. Also, just upstream of station 32, a foul-sewer siphon discharged frequently, since the load the sewer had been designed to carry had been exceeded, following extensive residential development. Station 33 was placed about a kilometre further south, downstream of the discharge from Lower Gornal Sewage Treatment Works.

The substratum at station 49 comprised mostly smooth stones embedded in sand, but the blockage of a culverted section downstream caused the deposition of much silt, so that no samples were taken over the period from June to December 1969. Gammarus pulex was usually the dominant member of the community (Appendix Tables 113 & 114), but there were periodic increases in the number of Simulium larvae and pupae, which probably derived their food from soil bacteria washed into the brook from farmland and woodland. Baetis rhodani nymphs occurred in small numbers and cased caddis were found occasionally. At times of low flow the brook was very narrow, often as little as 30 cm. wide.

Station 54 was established after finding a number of small, polluting discharges downstream of station 49. The effect of these discharges was an increase in the number of tubificids (Appendix Table 115). A comparatively large seasonal increase of Simulium larvae in September 1970 might also have been caused by slight pollution, though fairly large populations of Gammarus and Baetis were also found suggesting that the pollution was mild. After September 1971, Gammarus was always dominant.

A duplicate sewer to relieve the one which surcharged upstream of station 32 was completed in December 1971. Until this time, the bed at this station was usually covered by thick growths of sewage fungus. This phenomenon had a deleterious effect on the community, restricting the species to a very few, with tubificids and chironomids as the dominant groups (Appendix Tables 116 to 117). However, a number of Gammarus and Baetis were found probably because of adequate aeration. By March 1972 there was an improvement when Gammarus was the most abundant macroinvertebrate found, but by June enchytraeid worms had become dominant and, apart from March 1973, continued to be so.

Sewage fungus was found at station 33 only in December 1967 and March 1968. Table 4.8. (page 229) shows the results of chemical analysis of samples collected upstream and downstream of the discharge from Lower Gornal Sewage Treatment Works. The results cover a rather short period, but they indicate that the works effluent was not having a deleterious effect on the brook during that time. The monthly averages of chemical analysis of the final effluent from the Lower Gornal works from 1967 to 1973 are shown in Table 4.9. (page 230) and show that the effluent was well-nitrified and had a fairly low BOD loading throughout this period. During the first two years, the fauna was that typical of polluted waters (Hynes, 1960) with tubificid worms and chironomids dominant and C. riparius also common from time to time (Appendix Tables 118 & 119). The well-aerated conditions enabled Gammarus and Baetis to survive but not thrive. Asellus was poorly represented until the end of 1970 from which time it became increasingly common. Few molluscs were found throughout the period. There was little change in the species of the community up to June 1973, but the relative proportions of each species differed from season to season.

It is concluded that the brook remained polluted in

Month	BOD		NH_3		$NO_2 + NO_3$	
1969	u/s	d/s	u/s	d/s	u/s	d/s
July	-	-	1.5	0.4	6.0	33.2
Aug.	2.5	11.0	1.2	0.9	-	-
Sept.	38.7	18.0	9.0	2.4	1.2	1.4
Oct.	11.7	17.7	3.1	0.8	1.1	1.5
Nov.	11.2	11.5	2.4	0.8	6.0	22.0
1970						
Jan.	6.7	7.5	1.9	1.9	7.1	15.6
Feb.	9.7	10.8	1.5	0.9	5.6	10.8
Mar.	8.1	10.8	1.5	1.5	5.0	8.5
Apr.	9.7	16.6	0.5	0.9	11.1	25.1
June	3.3	7.5	2.0	0.9	3.6	14.6
Aug.	1.5	6.0	0.9	0.9	5.4	20.2
Sept.	2.7	8.7	2.4	2.6	5.8	15.4
Oct.	2.5	11.5	0.9	0.6	4.9	4.6
Nov.	7.0	10.0	0.3	0.6	2.8	11.8
1971						
Jan.	-	-	0.6	0.3	5.4	9.5
Mar.	2.5	8.7	1.2	0.3	6.2	16.7
Apr.	2.1	11.4	2.4	2.6	4.9	11.3

All figures in mg/l.

Table 4.8. Chemical Analysis of Stream Water: Bob's Brook upstream and downstream of the discharge from Lower Gornal S.T.W.

Date	BOD			NH_3			$NO_2 + NO_3$				Zinc
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Metals Av.	Av.
9/67-3/68	14	8	10	-	-	-	21	19	20	-	-
4/68-3/69	19	7	14	4.7	1.6	2.7	30	17	26	-	-
4/69-3/70	20	5	12	2.5	0.4	1.3	22	9	18	0.38	0.19
4/70-3/71	23	9	13	2.2	0.7	1.4	16	9	12	0.36	0.17
4/71-3/72	14	5	10	2.6	0.8	1.5	21	9	15	0.60	0.23
4/72-3/73	13	5	8	2.4	0.8	1.5	23	11	17	0.77	0.25

all figures in mg/l.

Table 4.9. Chemical Analysis of Final Effluent from Lower Gornal S.T.W. to Bob's Brook

the stretch downstream of station 32 from known and unknown sources some of which contained zinc (Table 4.3., page 201). The paucity of molluscs would suggest some pollution by heavy metals.

Stations 34, 35 and 50 (Holbeache Brook)

A short distance downstream of station 33, Bob's Brook flows into Holbeache Brook. This brook flows westwards from Dudley to Smestow Brook and has two sources. One source has been increasingly encroached upon by a municipal tip and the other source has been largely obliterated by opencast coal-mining. In addition to any pollution load introduced by Bob's Brook, a large volume of water containing high concentrations of suspended solids entered the upper part of the brook from the opencast mine. Despite some settlement in a small lake along its course, the water at station 34, just downstream of the confluence with Bob's Brook, was usually turbid. No samples were taken between September 1967 and September 1968 because a fallen tree downstream caused a blockage, which resulted in the water at station 34 being too deep to sample. At other times the fauna was often dominated by tubificids and chironomids. Asellus and Gammarus often occurred but rarely in large numbers (Appendix Tables 120 & 121). Simulium larvae first occurred in substantial numbers in June 1971 after which only seasonal (September) abundance was observed. Generally the brook was polluted at this station though after September 1972 some improvement could be discerned when Asellus and Gammarus were better represented, though as a part of greatly reduced community numbers.

Station 35 was about 1.5 km. further downstream and between it and station 34 is a small lake, Daffydingle Pool, in which some settlement of solids is thought to have taken place. Usually an extensive growth of Cladophora was evident at this station and until September 1972 Asellus was the dominant benthic macro-invertebrate. (Appendix Tables 122 & 123). Other species which developed fairly large populations at times were Pisidium sp., tubificids and in September and December 1970 Simulium larvae. The improvement noted upstream in September 1972 was marked at station 35 by a large increase in the number of Gammarus and though subsequently Asellus regained its former dominance Gammarus was still well represented.

About a kilometre further downstream at station 50, the 1970 peak in the Simulium population in the brook was found here only in September (Appendix Tables 124 & 125). A short distance upstream a small, clean tributary joins the brook, so that a further improvement in conditions was found with Gammarus often the dominant species. During the first few years, Asellus was also found in comparatively large numbers, but after the middle of 1971 it was found only rarely. It would seem that as conditions become cleaner, Asellus is unable to compete successfully with Gammarus. Baetis rhodani nymphs were found sporadically and became more numerous as conditions improved. Their low numbers towards the end of the survey period were thought to be caused by high flows rather than by worsening conditions. Hynes (1960) thought that the inability of Baetis rhodani to resist strong currents induced by flooding was the reason for the reduction of this insect in a Welsh mountain stream.

Zinc and copper were detected in samples taken from Bob's Brook and Holbeache Brook (Table 4.3., page 201), but concentrations were evidently rarely sufficient to seriously affect the fauna. If the watercourse from station 49 on Bob's Brook to station 50 on Holbeache Brook is considered, it will be seen that from a stream mostly dominated by Gammarus, a pattern can be observed through polluted stretches dominated by tubificids, enchytraeids or chironomids, to a recovery zone dominated by Asellus and sometimes Simulium, to a clean zone dominated again by Gammarus.

Stations 36, 37 and 38 (Penn Brook)

Penn Brook drains an area of farmland and residential development to the west of Sedgley. The major discharge to the brook was the effluent from Gospel End Sewage Treatment Works. Table 4.10. (page 234) shows the results of chemical analysis of the final effluent of this works from 1967 to 1973. More detailed results can be found in Tables 3.2. to 3.7. (Pages 123-128). Tables 4.11. and 4.12. (pages 235-236) give the results of chemical analysis of the stream water upstream and downstream of the works effluent during the period August 1969 to March 1972. Station 36 was a few metres upstream of the works effluent, station 37 an equal distance downstream and station 38 less than half a

Date	BOD			NH_3			$NO_2 + NO_3$			Total Metals Av.	Zinc Av.
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean		
4/67-3/68	31	12	22	-	-	-	21	14	17	-	-
4/68-3/69	20	15	18	7.2	2.8	-	37	3	19	-	-
4/69-3/70	23	6	11	27	0.52	4.0	31	7	16	0.32	0.15
4/70-3/71	15	8	12	4.2	1.1	2.1	29	14	20	0.31	0.15
4/71-3/72	23	6	14	4.6	1.3	2.2	27.	13	21	0.55	0.20
4/72-3/73	18	7	12	3.9	0.9	1.8	33	15	23	0.73	0.24

all figures in mg/l.

Table 4.10. Chemical Analysis of Final Effluent from Gospel End S.T.W. to Penn Brook

Month	BOD		NH_3		$NO_2 + NO_3$	
1969	u/s	d/s	u/s	d/s	u/s	d/s
Aug.	2.2	4.0	0.3	0.4	6.0	11.4
Sept.	5.5	6.0	0.3	0.6	2.2	10.4
Oct.	NIL	3.0	0.6	0.5	4.5	19.6
Nov.	1.0	9.0	0.2	1.8	1.0	2.7
Dec.	-	-	NIL	0.1	4.5	11.6
1970						
Jan.	3.2	5.2	0.3	1.8	3.9	12.8
Feb.	1.8	2.7	0.3	0.7	5.4	11.3
Mar.	1.8	3.0	0.2	0.6	4.9	11.0
Apr.	2.1	5.4	0.6	1.5	3.8	7.2
May	3.0	3.6	0.9	0.6	4.8	9.0
June	1.0	13.0	0.3	1.5	3.1	27.2
July	0.8	12.3	0.3	0.3	5.1	30.2
Aug.	1.3	4.3	0.3	0.6	4.9	9.2
Sept.	1.0	6.2	0.3	NIL	5.4	15.6
Oct.	0.1	10.8	0.2	1.9	4.2	27.9
Nov.	2.0	5.5	0.6	1.0	3.1	12.5
Dec.	3.1	6.2	0.9	0.6	4.6	12.5

All figures in mg/l.

Table 4.11. Chemical Analysis of Stream Water: Penn Brook upstream and downstream of the discharge from Gospel End S.T.W.

Month	BOD		NH_3		$NO_2 + NO_3$	
1971	u/s	d/s	u/s	d/s	u/s	d/s
Jan.	4.8	12.1	1.5	1.2	3.3	18.0
Feb.	2.3	7.3	1.8	1.8	3.1	10.5
Mar.	3.7	5.5	0.6	1.8	3.6	11.0
Apr.	2.4	6.4	NIL	0.3	3.6	11.3
May	-	-	-	-	-	-
June	3.3	6.4	1.5	0.6	3.8	13.1
July	2.2	7.1	0.3	0.3	2.8	15.6
Aug.	1.7	9.8	0.9	0.6	3.8	15.1
Sept.	2.2	24.2	NIL	1.2	6.6	14.0
Oct.	-	-	0.6	0.9	4.4	12.4
Nov.	0.7	1.5	0.6	1.2	3.2	6.4
Dec.	2.0	10.0	1.5	3.0	3.2	28.6
1972						
Feb.	3.0	6.7	NIL	0.3	5.8	12.4
Mar.	4.5	7.1	3.0	2.0	4.7	1.6

All figures in mg/l.

Table 4.12. Chemical Analysis of Stream Water: Penn Brook upstream and downstream of the discharge from Gospel End S.T.W.

kilometre downstream.

During most of the period studied station 36 was dominated by _Gammarus_ and _Baetis rhodani_ (Appendix Tables 126 & 127). September seasonal increases in the _Simulium_ population were also found with the numbers increasing in succeeding years due probably to domestic discharges to the surface-water sewer in the greatly expanded residential district upstream. In section 2.3.1. (page 81) a description was given of the problems at the Gospel End works especially from 1967 to 1969, when the new works was being built and its initial operating difficulties were being experienced. Although _Gammarus_ and _Baetis rhodani_ were found at station 37, it was tubificids, enchytraeids, chironomids, including _C.riparius_ (in 1967), and _Simulium_ which formed the major part of the community in the early years (Appendix Tables 128 & 129). _Simulium_ larvae and pupae, notably in September, were sometimes found in very large numbers and were obviously favoured by the steady supply of bacteria from the works effluent. _Simulium_ was found by Hawkes (1963a) to benefit from slight increases in organic loading in a stream. _Simulium_ was absent from December 1967 to September 1968, but was subsequently present (except June 1969) throughout each year. Similarly, at station 38, Simulium dominated the community almost throughout the period studied (Appendix Tables 130 & 131). In June 1969, both at station 37 and station 38, enchytraeid worms were dominant following the period of filter washing at the works (page 84).

As better purification was achieved after 1969, there was a gradual increase in the number of Gammarus and Baetis rhodani, but at both stations conditions were such that Simulium remained dominant and enchytraeid worms and chironomid larvae also persisted.

4.3. Application of biotic indices to data

The various biotic indices which have been devised were described and discussed in section 1.3.2. (page 38). Three of these indices, namely the Trent Biotic Index, the Chandler Score and a Diversity Index, have been applied to the results obtained from stream surveys (Appendix Tables 1 to 131) to compare their relative value in interpreting these results. The average annual value for each index for each station, from 1967 to 1973, are contained in Table 4.13 (page 239) and the monthly values for each sample from each station are contained in the Appendix Tables. Comparison of the monthly values with the annual averages show that although even for clean stretches, such as at station 1, there was sometimes considerable monthly variation in all three indices, persistently clean or persistently polluted conditions were revealed by annual averages.

There was not always agreement between the three indices, even when extremes of water quality were bein

STATION	1967/68			1968/69			1969/70			1970/71			1971/72			1972/73		
	T.B.I.	C.S.	D.I.	T.B.I.	C.S.	D.I.	T.B.I.	C.S.	D.I.	T.B.I.	C.S.	D.I.	T.B.I.	C.S.	D.I.	T.B.I.	C.S.	D.I.
1.	6	558	2.04	8	768	2.66	8	687	2.80	7	602	2.60	7	654	2.53	7	645	2.35
2.	6	544	2.27	7	601	1.87	7	544	1.75	6	488	1.86	7	570	1.37	7	460	1.42
3.	5	294	1.85	6	376	2.09	3	111	1.02	6	388	1.79	5	286	2.39	4	249	1.46
4.	5	286	0.97	4	224	1.08	2	117	1.43	4	162	1.29	2	128	1.24	3	142	1.63
5.	3	105	0.66	2	90	0.92	3	113	1.27	3	100	0.90	3	117	0.95	3	131	1.35
6.	3	117	1.27	3	109	0.78	3	115	1.23	3	97	1.13	3	105	1.01	3	105	1.04
7.	3	106	1.23	4	86	0.88	3	95	1.51	3	95	1.00	3	111	1.28	3	118	1.22
8.	3	120	1.70	3	109	1.56	3	119	1.68	3	126	1.81	4	146	1.62	3	123	1.35
9.	3	111	1.62	3	106	1.65	3	116	1.70	3	124	1.82	3	122	1.54	3	128	1.77
10.	-	-	-	-	-	-	-	-	-	-	-	-	3	111	1.75	3	114	1.68
11.	4	133	1.67	3	111	1.03	3	105	1.31	3	114	1.41	4	144	1.67	5	209	1.51
12.	3	70	0.55	3	66	1.03	3	91	1.20	3	102	1.37	3	109	1.16	3	110	1.15
58.	-	-	-	-	-	-	-	-	-	-	-	-	4	239	0.64	5	239	1.24
59.	-	-	-	-	-	-	-	-	-	-	-	-	3	97	1.29	4	179	1.29
13.	8	688	1.69	8	633	1.68	7	655	2.48	9	902	2.37	9	759	2.35	9	885	2.58
14.	5.	254	1.42	5	257	1.35	4	214	0.96	5	347	1.26	7	637	2.67	7	622	2.62
15.	5	177	1.21	6	355	1.39	5	286	1.20	4	224	1.59	6	379	1.35	6	368	1.64
16.	5	324	1.92	6	387	1.02	5	321	1.00	5	331	1.23	5	372	1.24	5	235	0.75
17.	6	508	1.66	6	402	1.23	5	270	1.02	5	251	0.79	4	197	0.80	5	253	1.41
18.	6	348	1.88	6	345	2.37	6	361	1.91	6	336	1.75	6	338	2.00	6	317	2.36
20.	1	73	0.04	2	137	1.03	2	87	0.71	2	90	1.35	2	102	0.85	3	124	1.42
21.	2	67	0.86	1	60	0.83	1	56	0.79	2	74	0.80	2	107	1.16	2	117	0.89
22.	1	37	0.42	1	48	0.57	1	42	0.57	2	71	1.20	2	51	0.63	2	59	0.95
24.	4	143	1.92	3	114	1.66	3	140	1.81	3	130	1.73	4	124	2.02	3	132	1.71
23.	4	133	0.64	4	157	0.99	4	135	0.86	4	163	0.85	5	331	0.88	5	355	0.77
51.	-	-	-	6	405	1.38	5	246	1.81	5	344	1.94	4	195	1.71	5	303	1.83
52.	-	-	-	5	304	1.64	5	329	1.40	5	287	1.38	6	358	2.16	6	454	1.79

STATION	1967/68			1968/69			1969/70			1970/71			1971/72			1972/73		
	T.B.I.	C.S.	D.I.	T.B.I.	C.S.	D.I.	T.B.I	C.S.	D.I.	T.B.I.	C.S.	D.I.	T.B.I.	C.S.	D.I.	T.B.I.	C.S	D.I.
25.	4	180	0.60	4	210	0.67	5	217	0.94	5	199	1.07	4	190	0.48	4	122	0.23
26.	2	94	1.25	43	180	1.09	0	15	0.21	4	160	1.54	4	131	1.57	4	152	1.49
27.	0	0	0	0	18	0.22	0	26	0.52	4	130	1.15	3	141	1.06	3	123	0.79
28.	1	19	0	2	54	0.84	1	32	0.41	3	93	1.72	4	119	1.41	4	146	1.20
55.	-	-	-	-	-	-	-	-	-	5	297	0.39	4	144	0.10	4	109	0.11
56.	-	-	-	-	-	-	-	-	-	1	32	0.36	1	24	0.25	1	33	0.26
29.	4	236	1.45	4	173	2.00	2	86	1.20	3	147	1.74	3	209	1.07	4	257	0.72
31.	5	357	1.90	5	334	1.21	2	92	1.14	2	106	1.49	3	153	1.44	4	290	0.94
49.	4*	188	2.02	5	229	1.14	6*	474	1.49	5	328	1.18	5	340	1.41	5	350	1.33
54.	-	-	-	-	-	-	-	-	-	5	229	1.78	5	279	1.17	5	290	0.88
32.	3	80	0.85	4	158	1.28	4	205	1.17	4	189	1.48	5	165	1.49	5	200	1.40
33.	4	181	1.02	4	237	1.56	5	232	1.97	5	281	1.86	4	163	1.26	5	242	2.17
34.	4	148	0.92	4	223	1.67	4	158	1.69	4	205	1.76	4	153	1.33	5	270	2.28
35.	3	132	0.96	4	147	1.19	3	111	0.56	4	172	1.06	4	181	0.96	5	280	1.48
50.	4*	122	1.78	5	254	1.31	5*	271	2.68	5	276	1.62	5	228	0.96	5	277	0.83
36.	5	241	1.27	5	221	1.60	5	261	1.68	6	376	2.21	5	264	1.51	5	240	1.57
37.	5	185	1.66	5	254	1.64	5	241	1.01	6	391	1.37	5	243	1.20	5	287	1.79
38.	4	151	1.11	4	227	1.03	4	229	1.17	5	273	0.71	5	294	0.64	5	280	1.03

* One Sample

assessed. The Trent Biotic Index in having only eleven broad categories was found to be the least sensitive index. The fact that it was based on the concept of presence or absence of groups was probably its greatest drawback. Seasonal absence of insects gave unrealistically low values and the appearance, perhaps as drift fauna, of even single specimens of higher scoring species such as Gammarus, mayflies or caddisflies, for example at station 11 (Appendix Tables 57-62), gave higher values than expected. Values of 5 or more may be considered to indicate clean conditions. According to Marstrand (1973) comparative Chandler Scores would be 110 and more, though because of the broader basis of the Chandler Score, there is considerable overlapping of Scores when equated with various Trent Biotic Index values. Applying this Score of 110, as a lower limit of fairly clean conditions to the results of the present survey, would include, at times, the results even from obviously polluted streams such as Mousesweet Brook, so a lower limit of 250 would be more applicable. Extending this, since there is a need to distinguish between different degrees of pollution; values between 200 and 250 would indicate mild pollution, those between 125 and 250 polluted conditions, those between 50 and 125 badly polluted and those below 50 grossly polluted. These figures are, of course, arbitary, but their application did generally reveal the significance of the community found at each station.

In his evaluation of diversity index values, Wilhm (1972) proposed that values below 1.0 indicated heavy pollution, those between 1.0 and 3.0 moderate pollution and those over 3.0 clean conditions. Mackay et al (1973), however, found values between 1.3 and 2.5 for unpolluted streams and values of 0 to 2.4 for polluted streams. This similar upper limit for each broad category of stream condition would indicate that the diversity index was of limited value. In the present study, wide divergences in diversity index were found even in clean streams. These were due, in part, to the fact that only the even distribution of species in a community is considered in assessing a diversity index and not the significance of the dominant species. Hence, dominance by Gammarus in Lutley Gutter (Appendix Tables 79-82) or in Ludgbridge Brook (Appendix Tables 99 and 100) resulted in very low diversity index values, whereas an even distribution of the fauna in a polluted stream such as Mousesweet Brook (Appendix Tables 87-90) or Wordsley Brook (Appendix Tables 101-106) gave comparatively high values. Diversity indices are, therefore, an expression of the evenness of species distribution. Uneven distribution may be the result of pollution or equally as the result of some physical effect such as substratum type or flooding.

The comparative value of the three indices in detecting the effects of polluting discharges on benthic fauna in the River Stour is shown in Fig. 4.13 page 243. All three indices showed the generally polluted nature of the River Stour from station 4 downstream. The Trent Biotic Index showed no difference in conditions at the stations between station 6 and station 12, whereas the

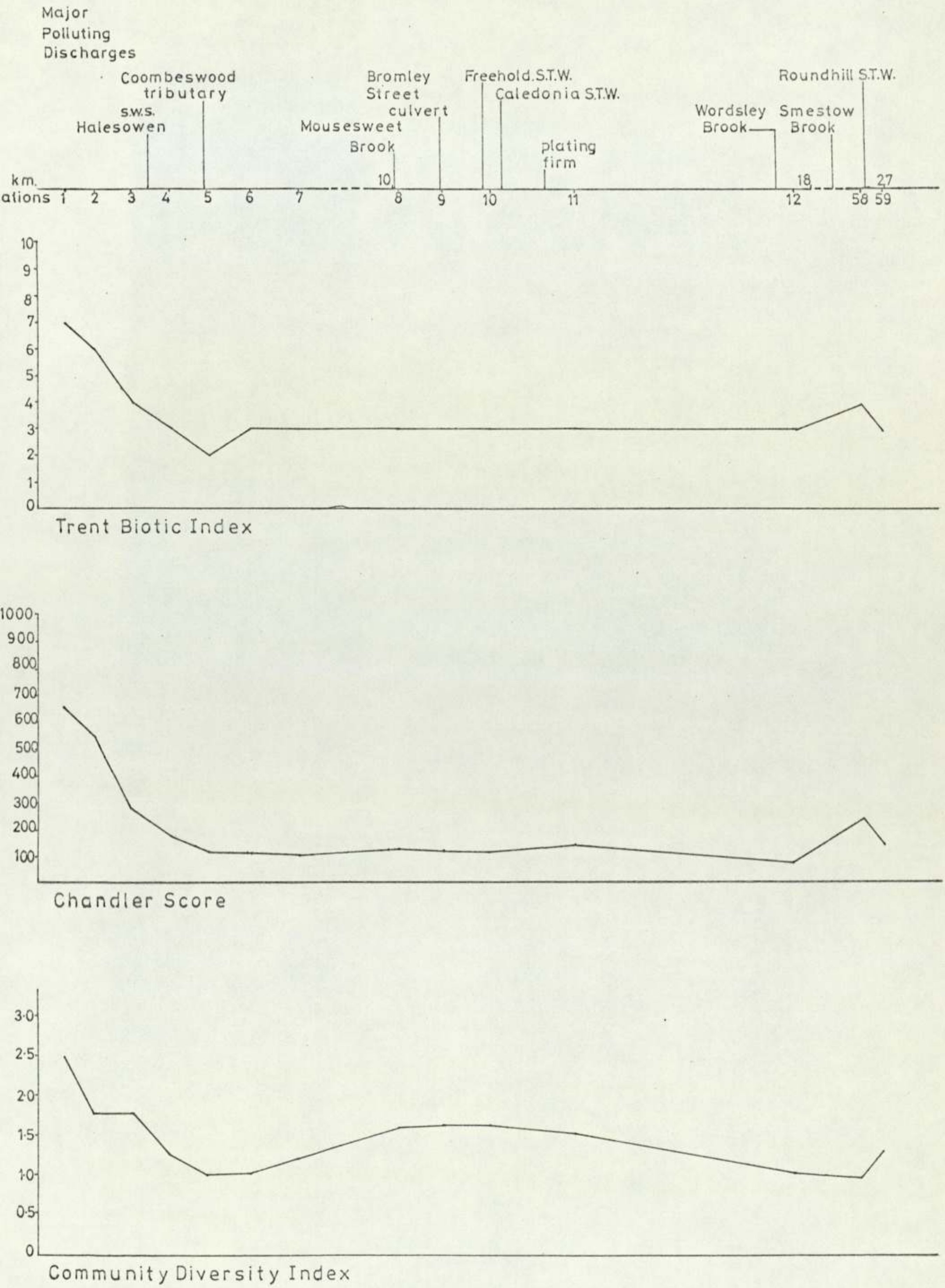

Fig. 4.13. Comparative sensitivity of three indices in detecting sources of polluting discharges to the River Stour (1967-1973)

Chandler Score and the Diversity Index showed slight changes from station to station. Both the Trent Biotic Index and the Chandler Score showed the improvement in conditions at station 58 and the deterioation at station 59, but the Diversity Index indicated a slight deterioration at station 58, because of the dominance by Asellus, and an improvement at station 59, where the numbers in each population were more alike.

A criticism which can be applied to all three indices is that none of them distinguished the effects of inorganic pollution from those of organic pollution. In a catchment such as that of the River Stour, where toxic metals were usually present, this was found to be a serious drawback. Further, none of the indices took into account the effects of the physical features of the substratum, so that the effects, for example, of sand in restricting the fauna even in clean streams sometimes led to low index values at clean stations such as 16, 17, 25, 49 and 50 (Appendix Tables 79-82, 99, 100, 113, 114, 124 and 125).

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Mild pollution can lead to the reduction of each population in a community without affecting the relative proportion of each population. This would still result in a high value for the Trent Biotic Index and the Diversity Index, but not for the Chandler Score. Patrick (1971) found that various diatom species were not killed by pollution, but they did cease reproduction, so that despite giving a high diversity index, their biomass was low. In Mousesweet Brook (Appendix Tables 85-90) the very small numbers of animals found were often evenly distributed amongst the

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species, thus yielding a comparatively high Diversity Index, but because of the species found, a low Trent Biotic Index and a low Chandler Score.

In summarizing, despite the accuracy implied by giving a numerical value to results, such values are limited or even misleading at times. Nevertheless, when evaluating all the drawbacks and advantages of each index, it was considered that the Chandler Score, despite its arbitary abundance levels and dubious position of some species, gave the most reliable interpretation of the results, mainly because it considered relative abundance of species and the relative tolerance of species to organic pollution.

Mackay et al. (1973) emphasized the need for base lines of physical and chemical parameters in devising a diversity index. Further to this there is an obvious need for an index which considers 1. seasonal variations in species abundance, 2. the effects of inorganic pollutants, 3. the effects of the amount of plant cover and the different microhabitat this introduces, and 4. one which gives different abundance values to carnivorous species from other trophic types.

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4.4. Conclusions

1. The upper stretches of the River Stour, Illey Brook, Lutley Gutter, Ludgbridge Brook, Dawley Brook, Bob's Brook and Penn Brook were usually clean.
2. Saltwells Brook, Black Brook and the lower part of Penn Brook and Lutley Gutter were mildly polluted.
3. Some stretches of Bob's Brook, Holbeache Brook,

Illey Brook and Dawley Brook were polluted.

4. The River Stour, downstream of Halesowen, was badly polluted by organic and inorganic discharges.

5. Mousesweet Brook and Wordsley Brook were badly polluted, Mousesweet Brook by discharges containing heavy metals and Wordsley Brook by organic and inorganic pollutants.

6. Tubificids, enchytraeids and Limnaea pereger were the most abundantly found species in organically polluted stretches.

7. Simulidae were abundant only downstream of mildly polluting sewage works effluents and here they were usually the dominant group.

8. Where organic pollution was slight, changes occurred in the relative proportions of the different species rather than in a loss of species.

9. In streams subject to inorganic pollution (from heavy metals), tubificids, enchytraeids and to a lesser extent chironomid larvae and Asellus were the most frequently found species.

10. Limnaea pereger, which was common in organically polluted zones, was adversely affected by discharges of heavy metals. Asellus was less adversely affected but was rare where concentrations of heavy metals were high. Stigeoclonium was the most tolerant alga to heavy metals.

11. Provided the water was well-aerated, clean-water species, such as Gammarus and Baetis rhodani, were able to survive where the substratum was covered with sewage fungus.

B. rhodani is not a clean water species – it is tolerant of mild pollution (organic).

12. In zones of recovery from pollution, tubificids were replaced as the dominant group by enchytraeids, midge larvae and then _Asellus_. _Asellus_ was replaced by _Gammarus_ where receovery continued.

13. Increased efficiency at Gospel End sewage treatment works, following the commissioning of new works, resulted in improvements in Penn Brook. The improved treatment of sewage at Roundhill, Freehold and Caledonia works resulted in noticeable improvements in the River Stour.

14. In clean streams, where sand formed a large proportion of the substratum, _Gammarus pulex_ was the dominant species.

15. There was a poor fauna where the substratum comprised a high proportion of sand or loose stones.

16. Discharges with high suspended solids content had the effect of reducing the fauna in the receiving watercourse to a few species. Iron deposits on the substratum had a similar effect.

17. Lack of molluscs at some stations was not always due to pollution but to an unsuitable substratum.

18. Deposition and accumulation of rubbish can have a profound effect on the stream fauna, eliminating those which require a constant current for survival.

5. Toxicity Studies

Herbert et al. (1965) reported that "in the Stour it seems that the only important lethal agent at this time was zinc". More recent analyses, done during these studies, would certainly indicate that, of the toxic metals, zinc was the predominantly occurring one in the River Stour, its tributary streams and also in sewage treatment works effluents.

The ecological studies of invertebrate communities in the River Stour and its tributaries revealed patterns of distribution, some of which were in response to the pollution load in individual watercourses (4.2.). The toxicity studies were undertaken in an attempt to define distribution in polluted watercourses in terms of certain parameters, mainly tolerance to various concentrations of zinc (sulphate) and dissolved oxygen. In addition, a number of tests were done to determine the tolerance of various invertebrate species to high temperatures, low pH and high pH.

5.1.1. Apparatus

The toxicity-testing laboratory streams were made from rigid plastic channeling (B.P. Plastics Ltd.) 2m. long, 10 cm. deep, and 10 cm. wide. Weirs made of 3 mm. thick Perspex frames covered with nylon mesh (Nybolt 20 g.g. 1000; 1 mm. apertures) were placed in plastic grooves fixed 30 cm. apart along each channel. Each channel, therefore, could be divided into a number of 30 cm. sections, or longer sections if some weirs were removed. By this means, different animals could be tested simultaneously, if required, e.g. predators and prey, or animals of the same species derived from different sources.

Each channel was drained by 6.5 cm. plastic drain-piping to a 25 l. rigid polythene, holding and mixing tank. The temperature of the water was controlled in the tank by a Baird and Tatlock long-reach Circon unit. A Griffin cooler unit was used also, for reducing temperatures to below ambient. Two outlet nozzles on the pump of the Circon unit circulated the water within the tank and pumped water to the channel. Tap water (bore-hole water, 80-140 mg/l. $CaCO_3$) was circulated through the system overnight prior to the test, in order to remove any excess chlorine. Analyses carried out during the toxicity testing programme showed that chlorine was never present in measurable quantities after this precaution.

In order to simulate stream conditions more closely, small stones (sufficient to displace 100 ml. of water) were placed in each section. The zinc sulphate solution being tested was introduced drop by drop into the system, at the outlet end of the channel so as to ensure maximum mixing. Two channels were used, one as the test channel and one as a control.

Since it was found, that re-aeration in the channels was too rapid to allow a low dissolved-oxygen concentration to be maintained, a Grant SB2 15l. water bath was used in tests involving the reduction of the D.O. content of the water. This water bath had its own heater and pump unit for maintaining a selected temperature and for circulating the water. The dissolved oxygen content was reduced by bubbling nitrogen into through the water. A piece of polystyrene tile on the water surface ensured minimum re- ?

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aeration of the water. The test animals were kept in a Perspex container (25 x 10 x 7 cms.) the ends of which were of nylon mesh. Small stones were placed at the bottom of the box and a Perspex lid, resting just below the surface of the water, ensured a minimum of re-aeration at this surface.

I cannot visualise the apparatus from this description.

The dissolved oxygen concentration and the temperature of the water in both the channels and the water bath were measured, using a pHOX 62T dissolved oxygen and temperature meter.

5.1.2. Determination of zinc concentrations in macro-invertebrates

In tests for zinc concentrations in macroinvertebrates from streams, the animals were not preserved but brought back to the laboratory as soon as possible after sampling and were killed by immersion in hot water. Each animal, whether directly from a stream or as a test animal from a toxicity test, was washed in deionised water to remove any extraneous matter such as silt particles, etc. The animal lengths were measured to the nearest 0.5 mm. *Gammarus* was measured straightened out, from the base of the antennae to the tip of the uropods; *Baetis* nymphs from the anterior of the head to the base of the cerci; *Asellus* from the base of the antennae to the tip of the uropods, and *Limnaea* and *Physa* were measured by the height of the shell. Each animal was put into separate, acid-cleaned, weighed, porcelain crucibles (Royal Worcester), and dried in an oven for 24 hrs. at 105°C. Snails were removed from their shells and the shells were discarded. After cooling, the crucibles were weighed to give the dry weight of each animal.

During the preliminary stages, the dried animals were transferred from the crucibles to Erlenmeyer flasks, where they were boiled in nitric acid, followed by perchloric acid and hydrochloric acid. After finding widely differing and high concentrations in animals from a clean stream, the flasks were tested as blanks (i.e. with the chemicals but without the animals) and large quantities of zinc were found. This was thought to be either from the glass itself or as a result of adsorption and transference from sample to sample (see 1.6.2.). Various cleaning methods were tried including those discussed in 1.6.2., but zinc was still found in the blanks. Eventually it was found, that by leaving out the flask stage of the procedure and by adding just nitric acid conc. to the crucibles containing the animals and heating until all the organic matter had been dissolved, the problem was resolved.

The resultant solutions were transferred to volumetric flasks and made up to 10 ml. with deionised water. If there was a residue of inorganic material, the crucibles were returned to the oven to dry and after cooling weighed. This weight was deducted from that of the dry weight of the animal previously found. Snails usually incorporate some grit in the gizzard and this would probably contribute to the residue found after dissolving snails in nitric acid. The crucibles were cleaned with boiling nitric acid and rinsed several times with deionised water. No measurable amounts of zinc were found in the nitric acid and no transference of adsorbed zinc to subsequent samples was found. The zinc concentration in each solution was measured using a Southern Analytical A3000 atomic absorption spectrophotometer.

5.2. Results and Discussion

The animals to be tested were kept in the experimental channels for approximately 24 hr. prior to testing. Depending upon the availability of the animals either ten, or more often, twenty individuals of each species were used in each test. Where possible the individuals within each species were of a similar size. *Asellus aquaticus* and *Gammarus pulex* were used in every test and, when available, *Baetis rhodani* and *Limnaea pereger* were also tested. When time permitted, animals killed in tests were digested in the manner described in 5.1.2. to determine the amount of zinc absorbed and adsorbed.

In order to determine base lines for the zinc experiments, preliminary tests were done to assess the range of tolerance to various physical and chemical parameters such as temperature, pH and dissolved oxygen concentration. The tests to determine the upper temperature tolerance of each species were carried out in the channels starting at 10°C and increasing by 5°C/hr. over a period of six hours. It was found that the upper tolerance limit of *Asellus* was 35°C, of *Limnaea* 37°C, of *Gammarus* 32°C to 33.5°C (depending upon its source) and of *Baetis* 33.5°C. Although *Limnaea* survived up to 37°C, individuals became immobile, though not insensitive, after the 30°C stage. Asellus and Gammarus began to show signs of distress after the 25°C stage. Dissolved oxygen concentration varied during the test from 93% at 10°C to 89% at 37°C. This is more meaningful in the form of $mg O_2/l$

Experiments to test pH tolerance limits were also carried out in the channels. The pH was increased by 0.5 units/hr. from pH 7.5 to pH 12.0 using sodium hydroxide (Na OH). Limnaea and Gammarus did not survive at pH 12.0, but only 5% of Asellus died at this value. At low values, pH was decreased by 0.5 units/hr. from pH 7.5 to pH 1.0 using HCl conc. Limnaea did not survive at values lower than pH 2.5; 63% of the Gammarus tested, 87% of the Baetis and all of the Asellus were unaffected at pH 1.0. Tests to determine the tolerance to low dissolved oxygen concentration were carried out in a water bath. At a dissolved oxygen concentration of 2mg/l at 10°C there was a wide divergence of response amongst the test species. Limnaea survived up to 48 hr. at this value and Baetis less than 6.5 hr., but Asellus showed only 30% and Gammarus 40% mortality after almost 20 days. Asellus was tested further at lower values; at a concentration of 0.5 mg/l at 20°C the median survival time was 11 hr. and at a concentration of 0.2 mg/l at 20°C the median survival time was 4.75 hr.

Although these tests were rather crude they did show that Asellus had a remarkably wide range of tolerance to the parameters tested. Gammarus showed a slightly narrower range of tolerance and Baetis, although showing tolerance to low pH and high temperature, was adversely affected by low dissolved oxygen concentration. Even though Limnaea showed the greatest tolerance of the four species to high temperatures, it was adversely affected by high and low pH and by low dissolved oxygen concentration. In its natural habitat, of course, Limnaea can come to the surface of the water to replenish its supply of oxygen and so avoid the effects of low dissolved oxygen content, but in the test vessel it was unable to do this. Krogh (1939), however, maintained that molluscs can "resist lack of oxygen for long periods". As shown above, in the present studies, when zinc was not present Limnaea survived at least 40 hr. at low dissolved oxygen levels.

The principal experiments to test the toxicity of various concentrations of zinc to selected benthic macro-invertebrates were carried out in fully aerated water at a pH of 7.0 to 7.2 and at a temperature of 10°C. These were supplemented with some tests done at 20°C, some at low dissolved oxygen concentrations and others at different hardness values. The concentrations of zinc tested were 0.5, 1.0, 2.0 and 4.0 mg/l using zinc sulphate ($Zn\ SO_4\ 7H_2O$) as the source of zinc.

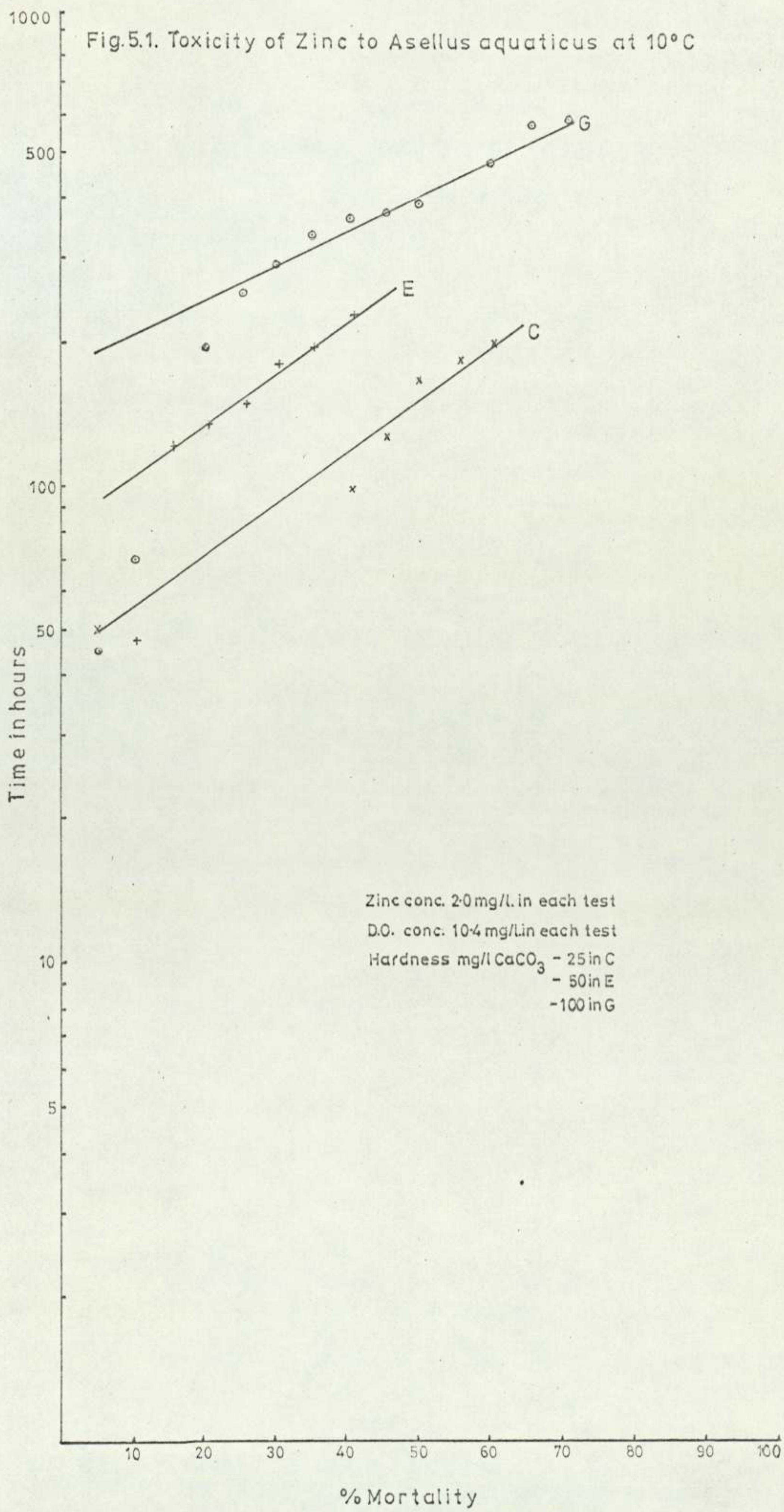
The results of the tests are shown in Table 5.1 (page 255) and graphically in Figs. 5.1. to 5.7. The effect on the toxicity of zinc when using water of different hardness values was well illustrated by the results of tests C, E and G. The median survival time of both Asellus and Gammarus was doubled when the hardness was increased from 25 to 50 mg/l. $Ca\ Co_3$, and doubled

Table 5.1. Results of Toxicity Tests

Species	Test	Zinc Conc. mg/l	Temp. °C	D.O. mg/l	Hardness $CaCO_3$ mg/l	m.s.t. hr.	%surviving %	duration of test hr.
A.aquaticus	A	0.5	20	0.5	120	135	-	-
	B	1.0	10	10.4	70	-	70	475
	C	2.0	10	10.4	25	140	-	-
	D	2.0	20	8.4	25	150	-	-
	E	2.0	10	10.4	50	290	-	-
	F	2.0	20	8.4	50	270	-	-
	G	2.0	10	10.4	100	400	-	-
	H	2.0	20	8.4	100	350	-	-
	J	4.0	10	10.4	70	230	-	-
	K	4.0	10	2.0	120	-	100	78
	L	4.0	10	1.0	120	-	80	120
	M	4.0	20	1.0	120	95	-	-
G.pulex	A	0.5	20	0.5	120	5	-	-
	B	1.0	10	10.4	70	90	-	-
	C	2.0	10	10.4	25	9.5	-	-
	D	2.0	20	8.4	25	4	-	-
	E	2.0	10	10.4	50	21	-	-
	F	2.0	20	8.4	50	14	-	-
	G	2.0	10	10.4	100	51	-	-
	H	2.0	20	8.4	100	23	-	-
	J	4.0	10	10.4	70	29	-	-
	K	4.0	10	2.0	120	47	-	-
	L	4.0	10	1.0	120	18	-	-
	M	4.0	20	1.0	120	3	-	-

Table 5.1. cont.

Species	Test	Zinc Conc. mg/1	Temp. °C	D.O. mg/1	Hardness Ca CO_3 mg/1	m.s.t. hr.
B.rhodani	A	0.5	20	0.5	120	<0.75
	B	1.0	10	10.4	70	380
	J	4.0	10	10.4	70	230
	K	4.0	10	2.0	120	77
	L	4.0	10	1.0	120	<0.5
L.pereger	A	0.5	20	0.5	120	17
	C	2.0	10	10.4	25	<0.75
	D	2.0	20	8.4	25	<0.75
	E	2.0	10	10.4	50	<1.0
	F	2.0	20	8.4	50	4.8
	J	4.0	10	10.4	70	3.75
	K	4.0	10	2.0	120	5.5
	L	4.0	10	1.0	120	<0.5
	M	4.0	20	1.0	120	4.0


1000
Fig.5.1. Toxicity of Zinc to Asellus aquaticus at 10°C
500
100
50
10
5
Time in hours
G
E
C
Zinc conc. 2·0 mg/l. in each test
D.O. conc. 10·4 mg/l.in each test
Hardness mg/l CaCO3 - 25 in C
- 50 in E
-100 in G
10
20
30
40
50
60
70
80
90
100
% Mortality

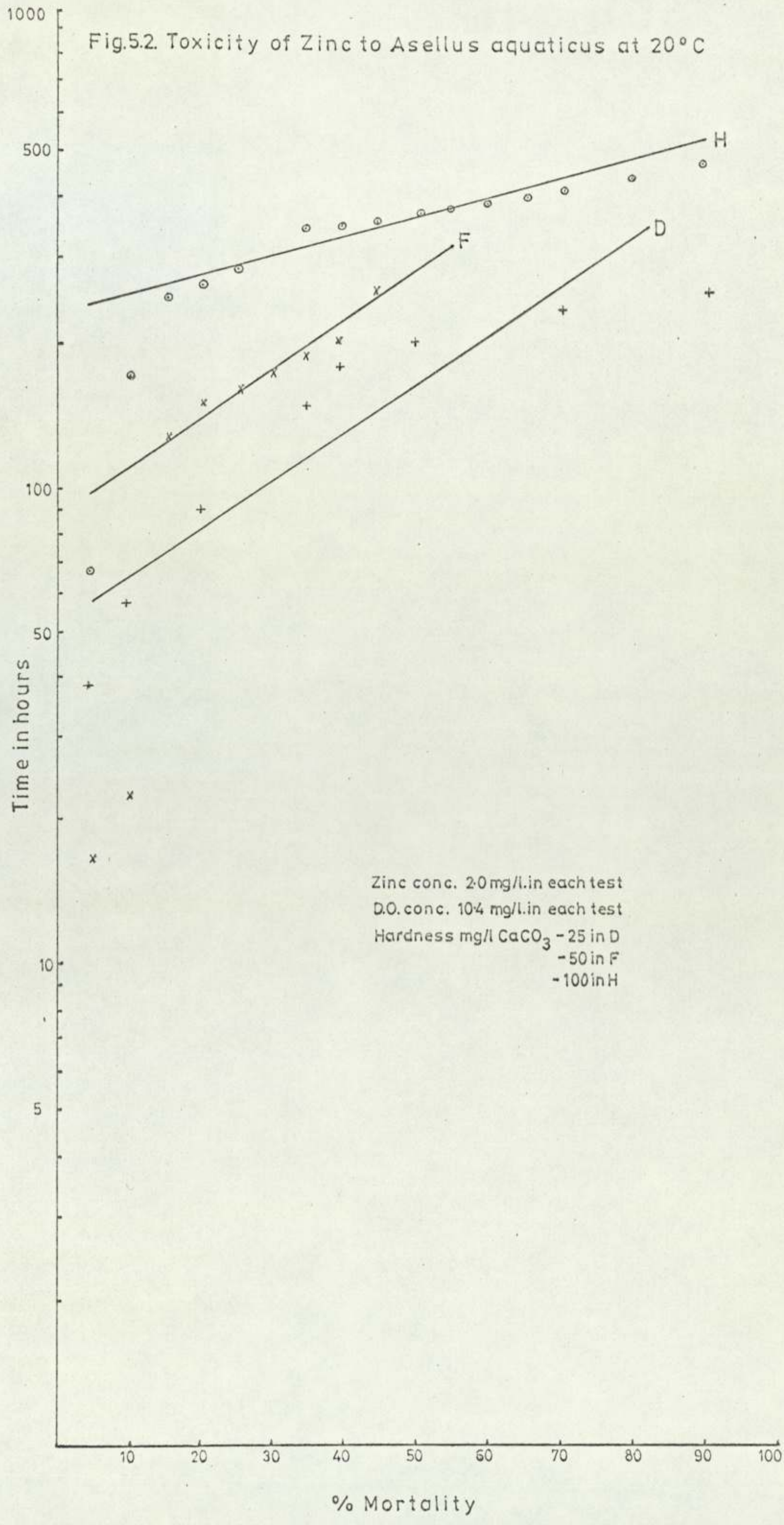


Fig.5.2. Toxicity of Zinc to Asellus aquaticus at 20°C
1000
500
100
50
10
5
H
F
D
Time in hours
Zinc conc. 2·0 mg/l. in each test
D.O. conc. 10·4 mg/l. in each test
Hardness mg/l CaCO3 - 25 in D
- 50 in F
- 100 in H
10
20
30
40
50
60
70
80
90
100
% Mortality

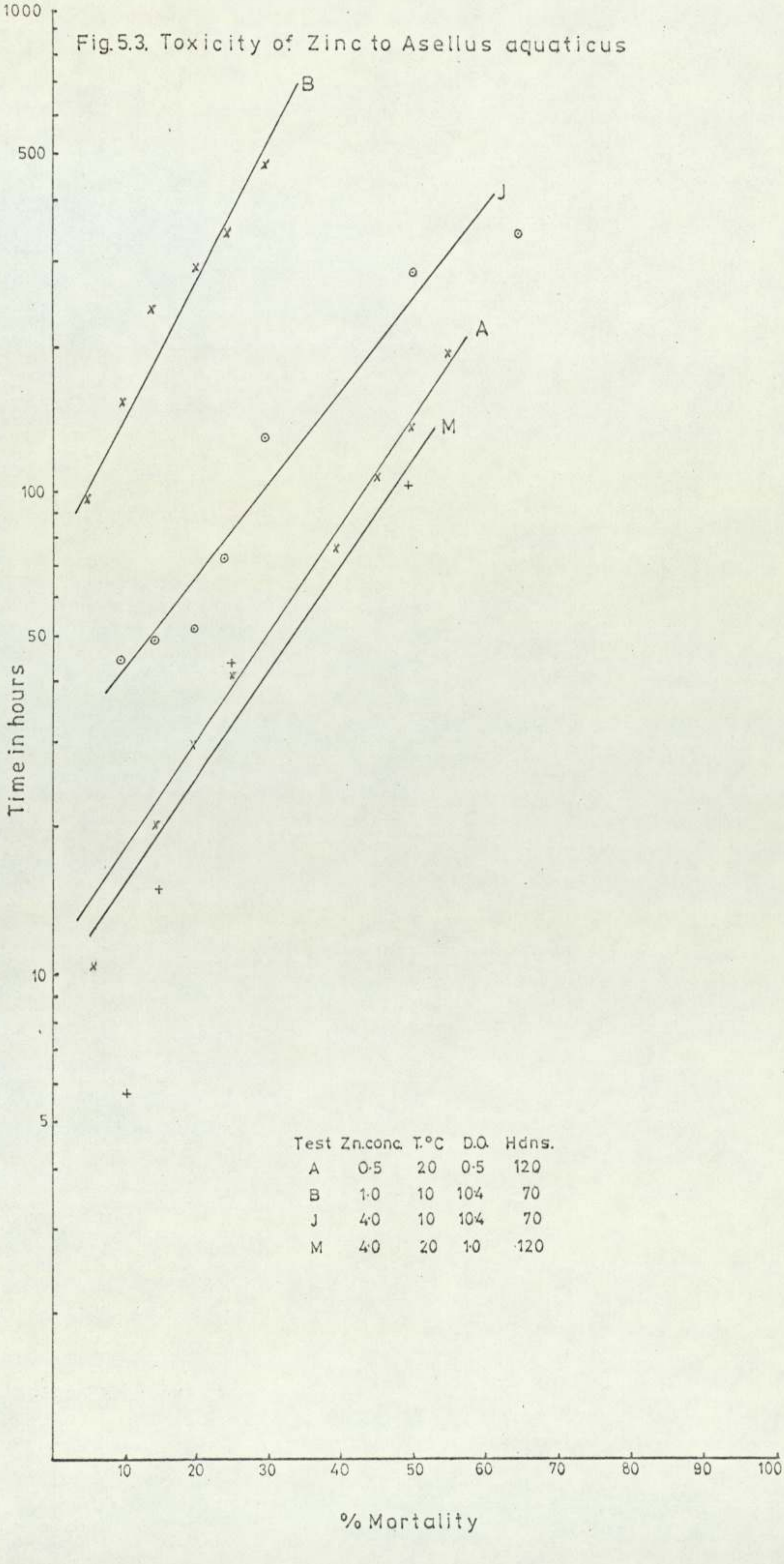
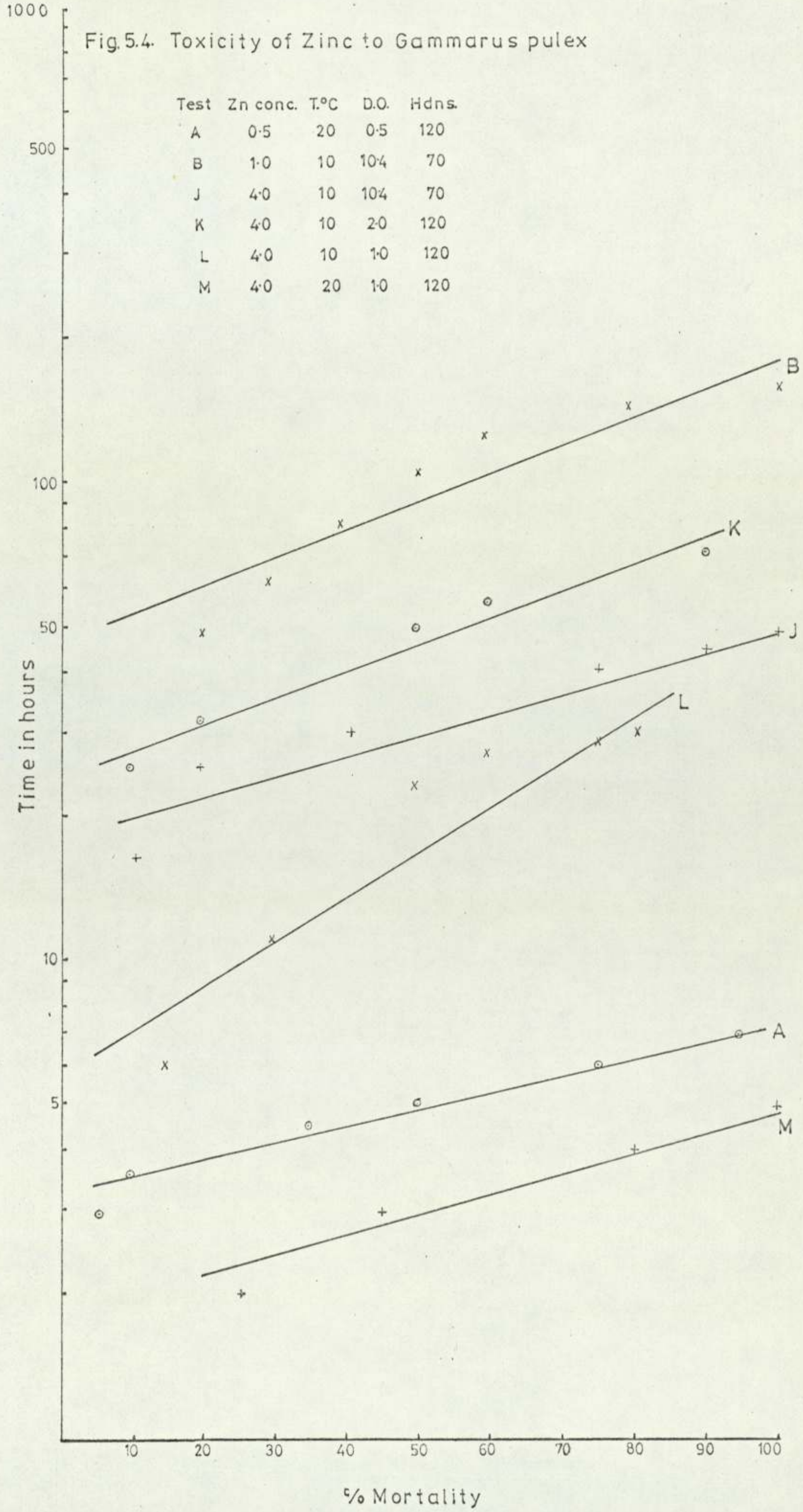


Fig. 5.3. Toxicity of Zinc to Asellus aquaticus


1000
Fig. 5.4. Toxicity of Zinc to Gammarus pulex
Test Zn conc. T.°C D.O. Hdns.
A 0·5 20 0·5 120
B 1·0 10 10·4 70
J 4·0 10 10·4 70
K 4·0 10 2·0 120
L 4·0 10 1·0 120
M 4·0 20 1·0 120
500
100
50
10
5
Time in hours
B
K
J
L
A
M
10 20 30 40 50 60 70 80 90 100
% Mortality

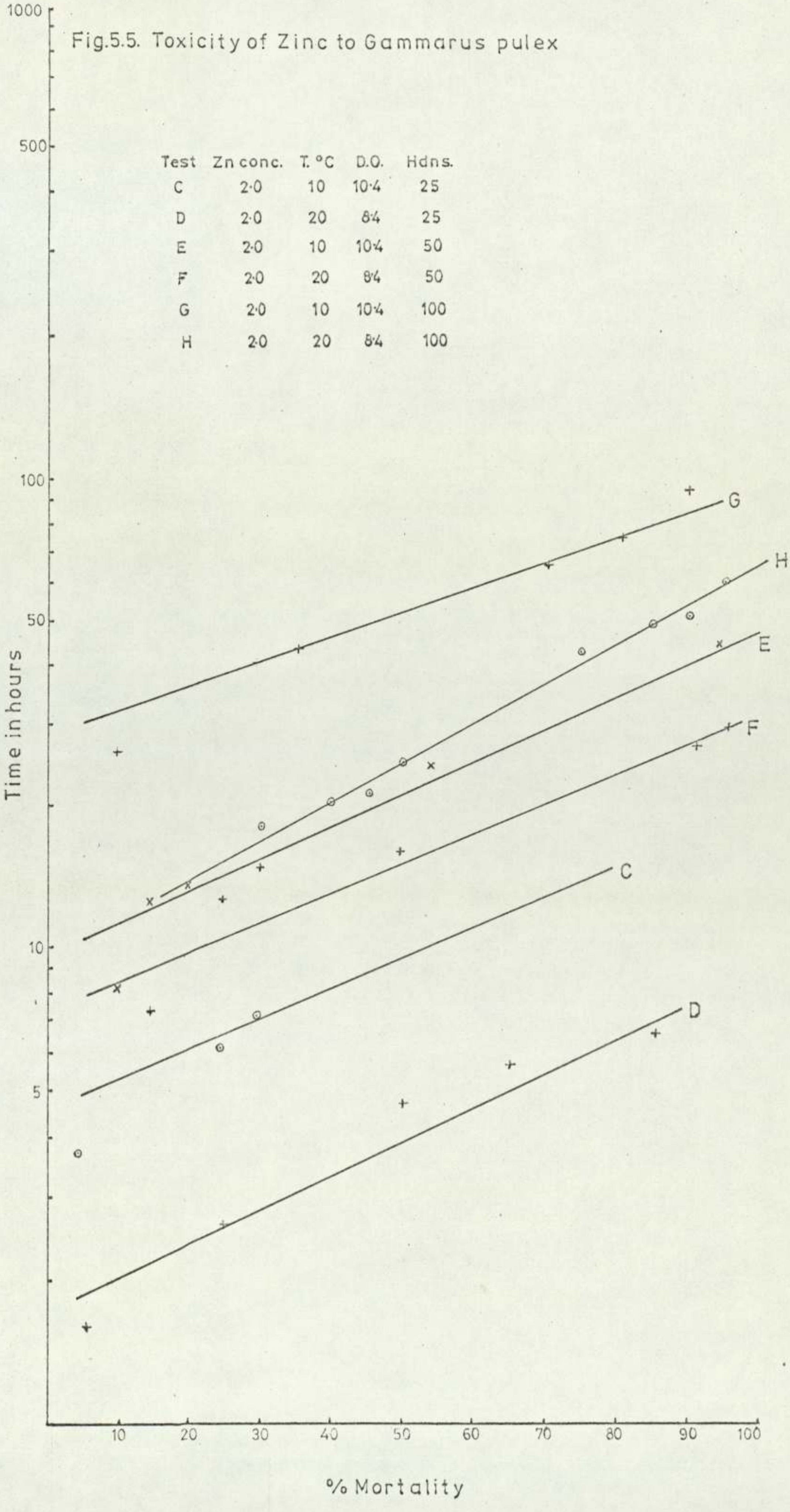
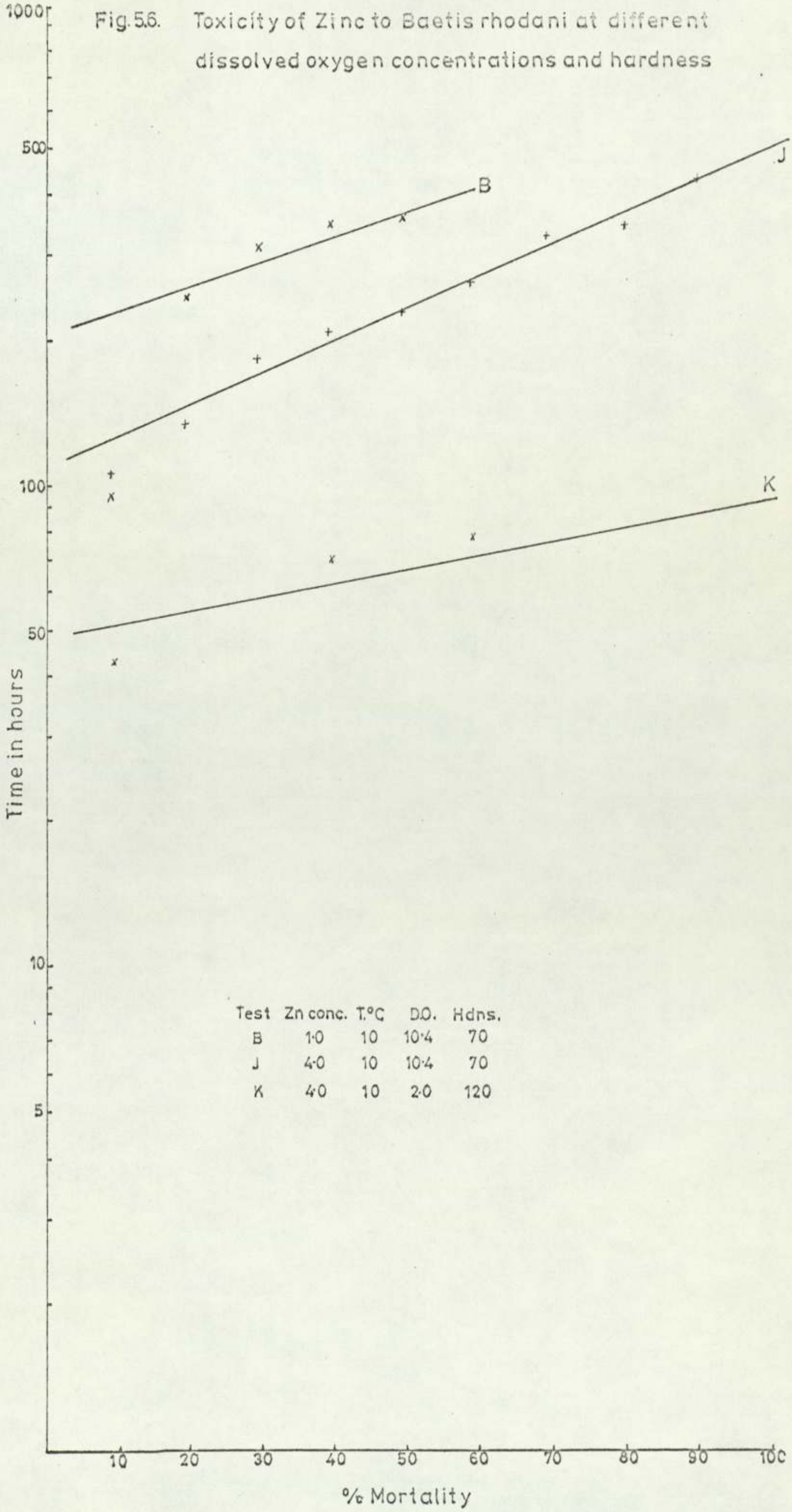


Fig.5.5. Toxicity of Zinc to Gammarus pulex

Test	Zn conc.	T. °C	D.O.	Hdns.
C	2·0	10	10·4	25
D	2·0	20	8·4	25
E	2·0	10	10·4	50
F	2·0	20	8·4	50
G	2·0	10	10·4	100
H	2·0	20	8·4	100

Fig. 5.6. Toxicity of Zinc to Baetis rhodani at different dissolved oxygen concentrations and hardness



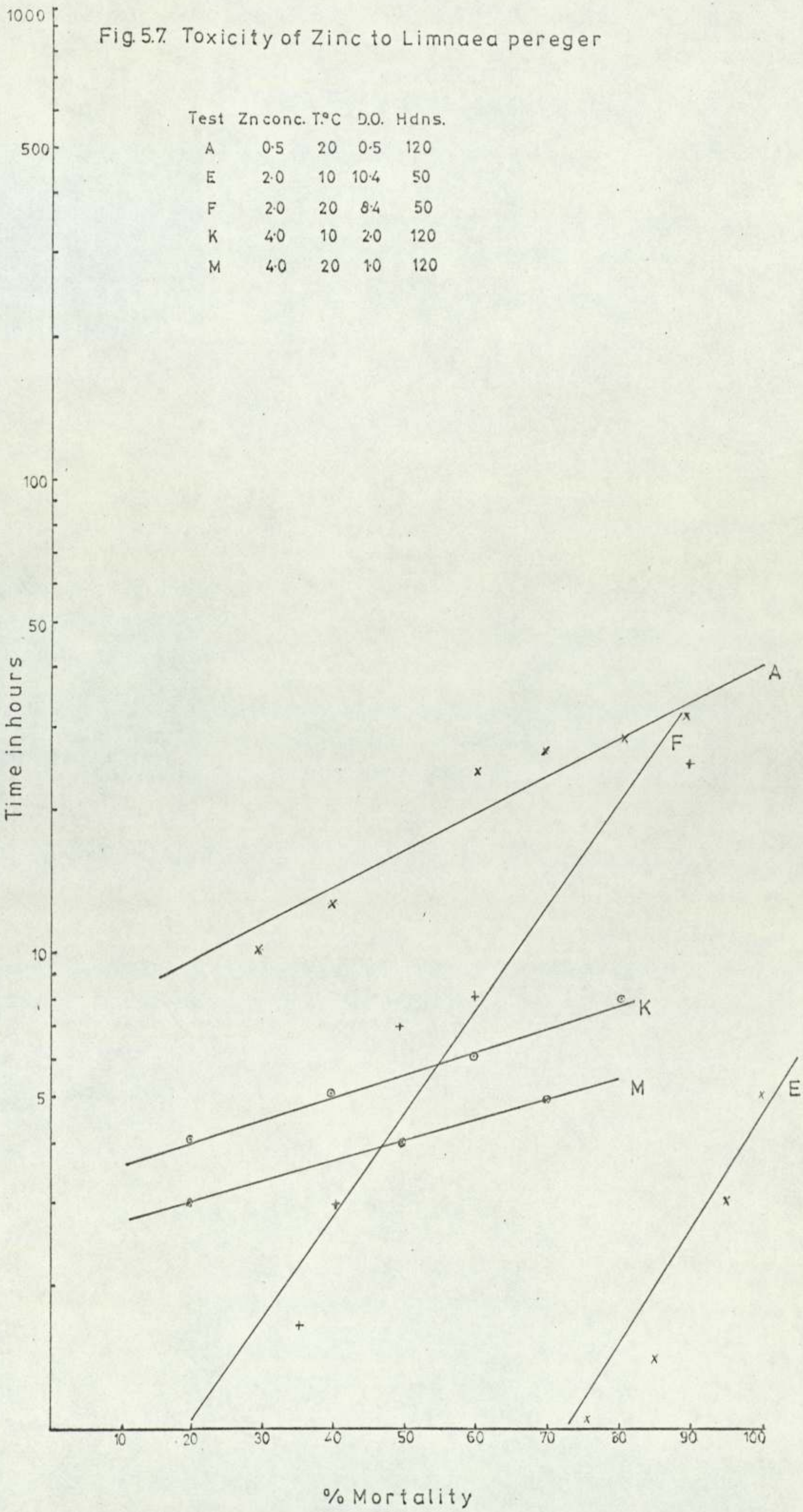


Fig. 5.7 Toxicity of Zinc to Limnaea pereger
Test Zn conc. T.°C D.O. Hdns.
A 0·5 20 0·5 120
E 2·0 10 10·4 50
F 2·0 20 8·4 50
K 4·0 10 2·0 120
M 4·0 20 1·0 120
Time in hours
1000
500
100
50
10
5
A
F
K
M
E
10
20
30
40
50
60
70
80
90
100
% Mortality

for Gammarus, but only by about 60% for Asellus when the hardness was increased from 50 to 100 mg/l. Evidently the effect of water hardness on the toxicity of zinc was more marked on Gammarus at these values than on Asellus. Martin (1972) found that the 48 hr. LC50 for Gammarus pulex was 2.4 mg/l of zinc when the water hardness was 100 mg/l, which ~~correlates~~ agrees well with the median survival time for Gammarus of 51 hr. (test G) in a zinc solution of 2.0 mg/l in the present study. When these tests were repeated at 20°C the median survival time for Asellus was very similar to the results obtained at 10°C for 25 and 50 mg/l, but at 100 mg/l it was slightly less. The median survival time for Gammarus at 25 mg/l was less than half of the time at 10°C, at 50 mg/l it was two thirds of that for 10°C and at 100 mg/l it was about 50%. It would appear, therefore, that at summer temperatures Gammarus would be less tolerant to zinc concentrations at the hardness values tested.

When the test water was well-aerated Baetis survived a zinc concentration of 4 mg/l for long periods (Test J) but reducing the dissolved oxygen concentration to 2.0 mg/l (Test K), 1.0 mg/l (Test L) and 0.5 mg/l (Test A) had marked effects. Gammarus and Asellus, however, were better able to survive these low oxygen concentrations. Limnaea, which was shown to survive higher temperatures than the other test species, tolerated 4.0 mg/l and a dissolved oxygen content of 1.0 mg/l for a longer period at 20°C (Test M) than at 10°C (Test L).

The results of these tests indicated that of the species tested Asellus was the most tolerant of the conditions imposed. The conditions had to be fairly severe (Test M) before Asellus was affected and even then the median survival time was 95 hours. An attempt was made to test zinc at higher concentrations, 16 and 20 mg/l, but because of rapid precipitation, it was found impossible to maintain these concentrations for prolonged periods.

The amounts of zinc absorbed by each species in five of the tests are shown in Table 5.2. (page 266). Considering that the mortality of Baetis in tests A and L was very rapid, the amount of zinc uptake was exceptional. Asellus which exhibited a similar degree of uptake survived for very much longer periods. In test L, the uptake by Limnaea was very much less than that of Baetis in the same period of time, which was possibly a reflection of the different rates of metabolism and amounts of movement shown by these two species. There was a greater uptake by Limnaea and Asellus at 20°C (test M) than at 10°C (test L) when testing zinc at 4 mg/l.

What is the mechanism of zinc absorption?

The uptake of zinc by Asellus from test water containing zinc at a concentration of 2.0 mg/l. showed a considerable divergence between test D, when the hardness was 25 mg/l and the temperature 20°C and test G, when the hardness was 100 mg/l and the temperature 10°C (Table 5.2., page 266). Possibly this uptake differential was a result of a respiratory rate difference, since this rate has been found to be raised at low temperatures by calcium ions in many species (Hynes, 1970, page 220). However, in test H, when the temperature was 20°C, the zinc uptake was greater still. Either calcium does not affect the

would like to see a statistical analysis of these results to ascertain whether significant differences exist

Table 5.2. Uptake of Zinc by Benthic Macroinvertebrates used in Toxicity Tests

Test	Zn conc. in test water	Species	Zinc conc. in test species Max.	Min.	Mean	m.s.t. in hr.
A	0.5 mg/l	A.aquaticus	1666	800	1352	135
		G. pulex	494	147	286	5
		L.pereger	630	311	428	17
		B.rhodani	1680	789	1362	<0.75
D	2.0 mg/l	A.aquaticus	909	307	488	150
G	2.0 mg/l	A.aquaticus	3157	1212	2089	400
		G. pulex	964	500	702	51
H	2.0 mg/l	A.aquaticus	5125	1162	3526	350
		G. pulex	892	347	595	23
L	4.0 mg/l	A.aquaticus	2222	1090	1706	>120
		G. pulex	909	275	564	18
		L.pereger	341	208	272	<0.5
		B.rhodani	2352	1102	1595	<0.5
M	4.0 mg/l	A.aquaticus	2555	1448	1943	95
		G. pulex	833	256	567	3
		L.pereger	536	258	363	4

respiratory rate in crustaceans to a marked extent, or alternatively higher temperatures have a greater effect on this rate and so zinc is absorbed more rapidly.

Although a greater amount of zinc was absorbed and adsorbed by Asellus than Gammarus, Table 5.1. (page 255) shows that the median survival time of Asellus was much longer, so that in fact the rate of zinc uptake (μg Zn absorbed/g. animal dry weight/hr.) by Asellus was much less than that of Gammarus. In test A, the rate of uptake by Limnaea, a less active animal than either of the two crustaceans tested, was less than that of Gammarus. In tests L and M, however, there was a contrast in the rate of uptake. At 10°C (test L) Limnaea showed a greater rate of uptake, but at 20°C (test M) Gammarus showed a greater rate. Presumably, at the higher temperature, which in the preliminary tests it was found Limnaea was better able to tolerate, Gammarus respired at a faster rate and, therefore, absorbed a greater proportion of zinc. Baetis, in test L, was found to absorb zinc at a greater rate than any of the other species tested, possibly because it is a comparatively active species.

Selected species from each sampling station were prepared for analysis of zinc content by the method described in 1.6.2. (page 63). The results of this analysis are shown in Table 5.3. (page 268). The maximum, minimum and mean concentrations are given for each species. At some stations, 1, 11, 58, 21, 22, 33 and 34, the zinc content of two species has been analysed. Comparison of the zinc concentration in each species at these stations

Table 5.3. Zinc Content of Benthic Macroinvertebrates from the Stour Catchment

Station	Species (length mm.)	Zinc Content µg/g Max.	Min.	Mean
R. Stour	1. Baetis rhodani (7.0-9.0)	800	173	533
	1. Gammarus pulex (11.0-15.0)	67	23	44
	2. G. pulex (9.0-12.5)	86	70	74
	3. G. pulex (12.0-17.5)	135	84	101
	4. Asellus aquaticus (6.0-8.0)	416	294	348
	5. A.aquaticus (6.5-8.0)	615	363	465
	6. A.aquaticus (6.0-7.5)	600	210	349
	7. A.aquaticus (5.0-8.5)	375	192	253
	8. A.aquaticus (5.5-8.5)	769	190	479
	9. A.aquaticus (5.0-7.5)	1142	551	773
	10. A.aquaticus (4.5-8.0)	1315	625	875
	11. A.aquaticus (6.0-9.5)	600	266	464
	11. Limnaea pereger (9.0-15.0)	451	178	325
	12. A.aquaticus (5.5-8.0)	521	307	394
	58. A.aquaticus (5.0-8.5)	1043	600	832
	58. G. pulex (11.0-12.0)	307	146	203
	59. A.aquaticus (5.0-8.0)	833	322	584
Illey Brook	13. G. pulex (10.5-17.5)	247	173	204
	14. G. pulex (9.0-11.5)	294	136	222
	15. G. pulex (11.0-15.0)	227	119	175
Lutley Gutter	16. G. pulex (11.0-16.5)	98	81	89
	17. G. pulex (13.0-16.5)	137	57	84
	18. G. pulex (15.0-17.0)	173	88	129
Mouse-sweet Brook	20. Chironomid larvae (6.0-8.0)	833	714	780
	21. A.aquaticus (4.0-7.0)	500	294	385
	21. L. pereger (6.0-8.5)	822	446	557
	22. Chironomid larvae (6.0)	3333	2500	3041
	22. L. pereger (5.5-10.0)	1538	1011	1319
	24. A.aquaticus (4.0-8.0)	2142	909	1341

Table 5.3. cont.

Station	Species (length mm.)	Zinc Content µg/g		
		Max.	Min.	Mean
Saltwells Brook	23. *G. pulex* (11.0-17.5)	163	85	119
Black Brook	51. *G. pulex* (10.0-16.5)	209	89	147
	52. *G. pulex* (10.0-13.0)	279	118	172
Ludgbridge Brook	25. *G. pulex* (12.0-16.5)	186	79	137
Wordsley Brook	26. *A.aquaticus* (5.0-8.0)	1666	666	1095
	27. *A.aquaticus* (4.5-8.0)	769	312	482
	28. *A.aquaticus* (5.5-7.5)	483	312	391
Dawley Brook	55. *G. pulex* (11.5-18.0)	231	138	174
	56. Tubificidae	-	-	173
	29. *L.pereger* (10.0-12.5)	714	393	491
	31. *A.aquaticus* (5.0-8.0)	757	340	516
Bob's Brook	49. *G. pulex* (11.0-15.0)	130	44	84
	54. *G. pulex* (10.0-18.0)	93	40	57
	32. *G. pulex* (11.5-14.5)	158	63	119
	33. *G. pulex* (12.5-18.0)	179	134	161
	33. *A.aquaticus* (6.5-8.0)	350	156	251
Holbeache Brook	34. *G. pulex* (14.0-16.0)	233	173	193
	34. *A.aquaticus* (6.5-8.0)	227	187	208
	35. *G. pulex* (12.0-17.0)	301	117	205
	50. *G. pulex* (10.5-15.0)	208	125	159
Penn Brook	36. *G. pulex* (9.5-17.0)	227	82	140
	37. *G. pulex* (12.0-15.5)	163	46	83
	38. *G. pulex* (11.5-16.5)	194	138	159

shows interesting differences. At stations 1, 58, 33 and 34, it can be seen that the zinc concentration in Gammarus pulex was usually considerably less than in either Baetis rhodani (station 1) or Asellus aquaticus elsewhere. In the conditions of the toxicity tests, discussed above, it was shown that zinc uptake by Gammarus was greater over a particular period than by most other species. It is possible that the gammarids analysed were younger than either the baetids or Asellus and had, therefore, less time in which to absorb zinc. At station 11, a greater concentration of zinc was found in Asellus than in Limnaea, but at station 21 the opposite was found. Further downstream, at station 22, the concentration of zinc in midge larvae was over twice as much as in Limnaea.

The results also reveal that there was a considerable background of zinc even in clean streams such as Lutley Gutter, Ludgbridge Brook and Illey Brook. Read (1947) cited limestone as one of the common sources of zinc. As described in section 2.1.1. limestone strata are found in the area studied.

5.3. Conclusions

1. *Asellus aquaticus* was found to be tolerant to fairly high temperatures, high and low pH and low dissolved oxygen concentration. Why not give actual values?

2. The other crustacean tested, *Gammarus pulex*, was found to have a narrower range of tolerance to these parameters.

3. *Limnaea pereger* was the most tolerant to high temperature of the species tested, but less tolerant to extremes of pH and to low dissolved oxygen concentrations.

4. *Baetis rhodani* was tolerant to low pH values and high temperature but sensitive to very low dissolved oxygen concentrations.

5. *Asellus* was the most tolerant of the species tested to various concentrations of zinc at different temperatures, hardness and dissolved oxygen values.

6. *Baetis* was more tolerant than either *Gammarus* or *Limnaea* to zinc when the dissolved oxygen was not less than 2.0 mg/l, but below this level the effect of low dissolved oxygen on *Baetis* was severe.

7. *Limnaea* was generally intolerant to zinc, but its survival was usually longer at the higher temperature when tests were done at two temperatures.

8. *Gammarus* showed greater tolerance to zinc than *Limnaea* did, but it too was adversely affected in zinc solutions with low dissolved oxygen values and high temperatures (tests A and M).

6. Synthesis of Data from Stream Studies and Toxicity Studies

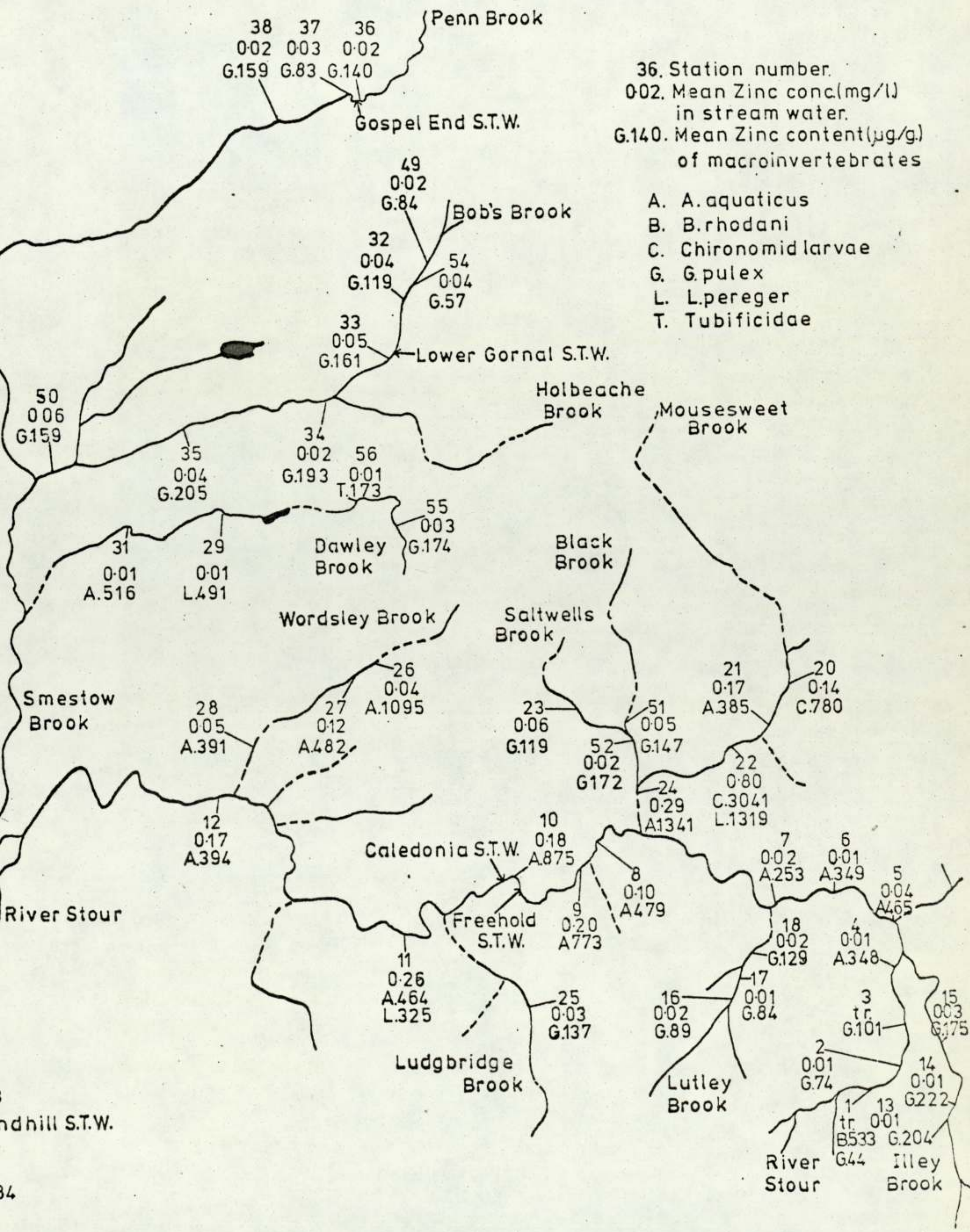
The mean concentration of zinc found in selected species at each station (Table 5.3., page 268) and the mean concentration of zinc from seasonal samples of water at each station (Table 4.3., page 201) are compared in Fig. 6.1. (page 273) and in Fig. 6.2. (page 274).

Not surprisingly the highest concentrations of zinc in the stream water and in the benthic fauna coincided at many stations. In the River Stour, highest zinc concentrations were found from station 8 downstream, much of it being derived from Mousesweet Brook. Further upstream, for example at station 1, only very small amounts of zinc were found. Little zinc was found in Gammarus here (Table 5.3., page 268), but comparatively large amounts were found in Baetis rhodani. Possibly the longer life cycle and the greater rate of zinc uptake (Table 5.2., Test L, page 266) of Baetis were responsible for this difference.

Has it?

As discussed in section 5.2., Asellus was found to be remarkably resistant to quite high concentrations of zinc, Baetis and Gammarus were somewhat less resistant and Limnaea was comparatively intolerant. That some of the streams studied were subject to discharges containing high concentrations of zinc was shown by the results given in Tables 4.3. (page 201) and 5.3. (page 268). It would be advantageous if the distribution of the benthic macroinvertebrates could be explained simply in terms of the degree of zinc concentrations at each station, but the River Stour and its tributaries, no less than other river systems, were found to be subject to a number of discharges, both organic and inorganic in nature. This complexity

Mean concentrations of Zinc found in stream water and in macroinvertebrates



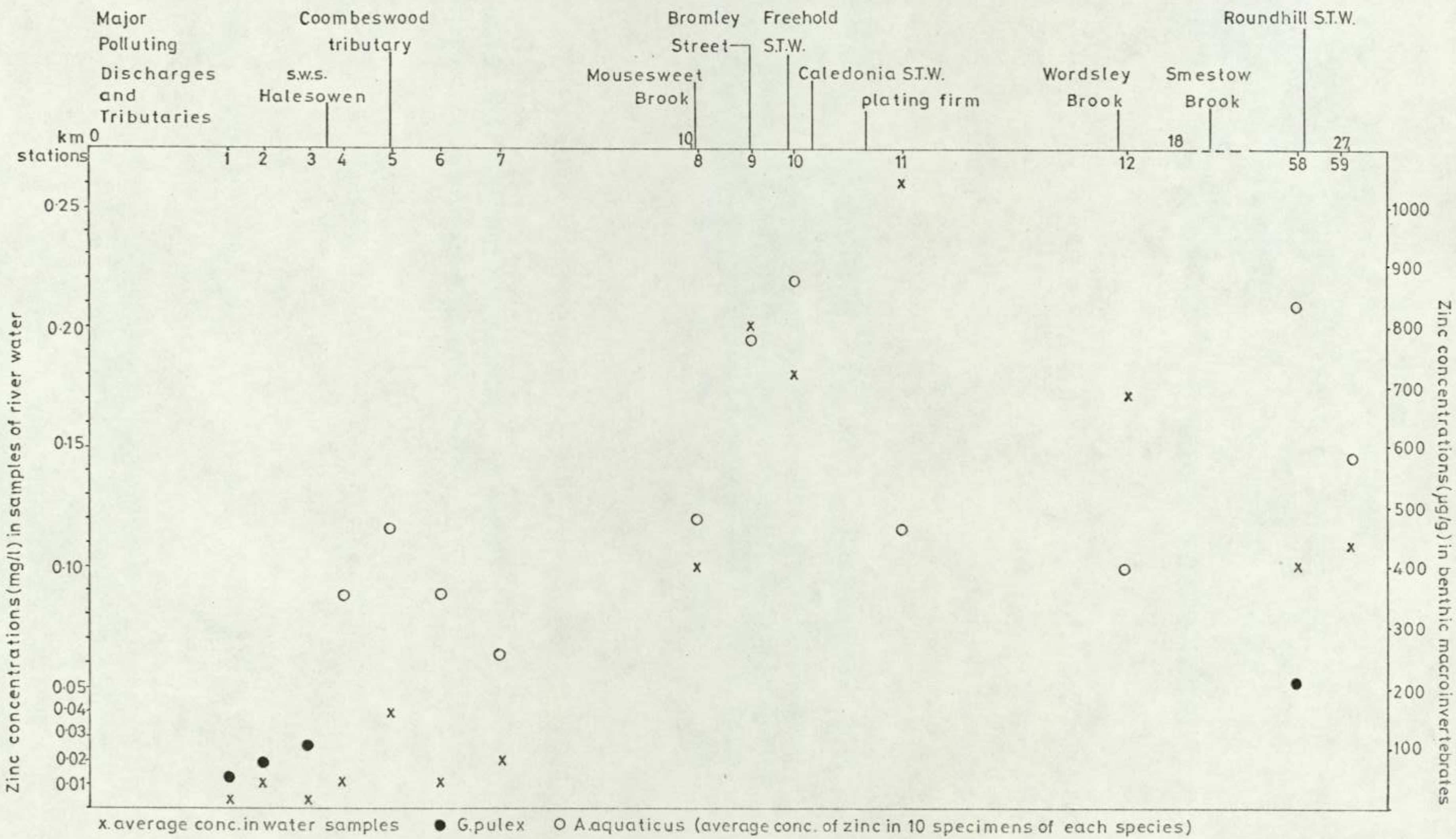


Fig. 6.2. Concentration of zinc in river water (R. Stour) and in macroinvertebrates

of chemical pollution made it impossible to strictly correlate fauna distribution with zinc concentration. However, where zinc concentrations were found to be high, it was thought that a comparison of the community composition at such stations could be beneficial.

Consistently high zinc concentrations were not found until station 8 in the River Stour. (Fig. 6.2., page 274). It was shown in section 4.2. that the fauna comprised mostly Asellus, tubificids, enchytraeids and Limnaea. Limnaea was sometimes comparatively rare when zinc concentrations were fairly high. Zinc concentrations in water samples were usually consistently higher further downstream at station 11, but smaller concentrations were found from fauna analysis. During much of the study period, Asellus was dominant at this station and also at station 12, but decreases in Asellus and in Limnaea and increases in tubificids seemed to coincide with higher zinc concentrations. Although Limnaea showed seasonal increases in September, numbers seemed to be rapidly reduced subsequently. Is not this to be expected?

The effect of zinc on Limnaea was more marked in Mousesweet Brook. At station 22 (Appendix Tables 89 & 90) very low numbers of Limnaea coincided with high zinc concentrations throughout the study period. Further upstream at station 21 and further downstream at station 24 comparatively large populations (especially at station 21) of Limnaea occurred when zinc concentrations in the water were low. Conversely, these populations were considerably reduced when zinc concentrations were high. Low populations usually occurred when concentrations of zinc were found to be in excess of 0.3 mg/l. The effect of chrome, however, especially at stations 21 and

22 cannot be disregarded when assessing fluctuations in various populations.

Although zinc was the most frequently found metal in Wordsley Brook, copper (Table 4.3., page 201) and to a lesser extent nickel and lead were also found. In addition, the brook received polluting discharges from a refuse tip, from a steel works and iron from sludge tipping, so it was not possible to separate the effects of zinc on the benthic fauna from those induced by other pollutants.

High concentrations of zinc were not found in the water of Dawley Brook, but were found in Limnaea and in Asellus at stations 29 and 31 respectively. Zinc concentrations in Limnaea were comparable with those found in Limnaea at stations 11 and 21, and in Asellus with those found in Asellus at some stations in the River Stour.

The results from the stream surveys (Appendix Tables), when considered in conjunction with the data obtained from the zinc toxicity tests, may be interpreted and summarized as follows. Where zinc concentrations were high (Table 5.3., page 268) the fauna was restricted in numbers of species. In streams such as Mousesweet Brook, where Limnaea occurred this species was reduced in numbers when zinc concentrations were high. This reflected the intolerance to zinc by Limnaea found in the toxicity tests (Table 5.1., page 255). The paucity of Limnaea in many of the tributary streams, however, was possibly because of a lack of suitable food or because of the sandy nature of the substratum. Gammarus and Baetis rhodani were common in these streams, where also zinc concentrations were usually very low. Asellus, which was found in the toxicity tests to survive comparatively high concentrations of zinc for prolonged periods, occurred throughout the River Stour downstream of Halesowen. It is unfortunate, that the distribution of *Asellus* could not be directly correlated with zinc concentrations found in spot samples of river water. None of the spot samples contained more than 0.6 mg/l of zinc, but it is reasonable to assume that zinc did occur in higher concentrations, moreover, the generally low numbers of animals found, including *Asellus*, would indicate that toxic metals were invariably present. Only at stations 22 and 24 (Mousesweet Brook) were comparatively high concentrations of zinc found in the stream water (Table 4.3., page 201). Since *Asellus* was usually absent from station 22, it would seem likely that this absence was caused by discharges containing high concentrations of heavy metals, notably zinc and chrome. The small number of *Asellus* found at station 24 contained comparatively high concentrations of zinc (Table 5.3., page 268). Where the zinc content of the water was generally low but the organic content was high, such as at station 35 (Holbeache Brook), *Asellus* was comparatively common.

The occurrence of *Asellus* and *Gammarus* at various mean zinc concentrations in stream water is shown in Fig. 6.3., (page 278). *Gammarus* was confined to streams where mean zinc levels were generally below 0.1 mg/l, whereas *Asellus* occurred at levels up to at least 0.3 mg/l. *Asellus* was absent at mean zinc concentrations of 0.8 mg/l, but it was not evident from field studies which levels between 0.3 and 0.8 mg/l were toxic to this species. The absence of *Asellus*, where mean zinc levels were below 0.05 mg/l, can probably be attributed

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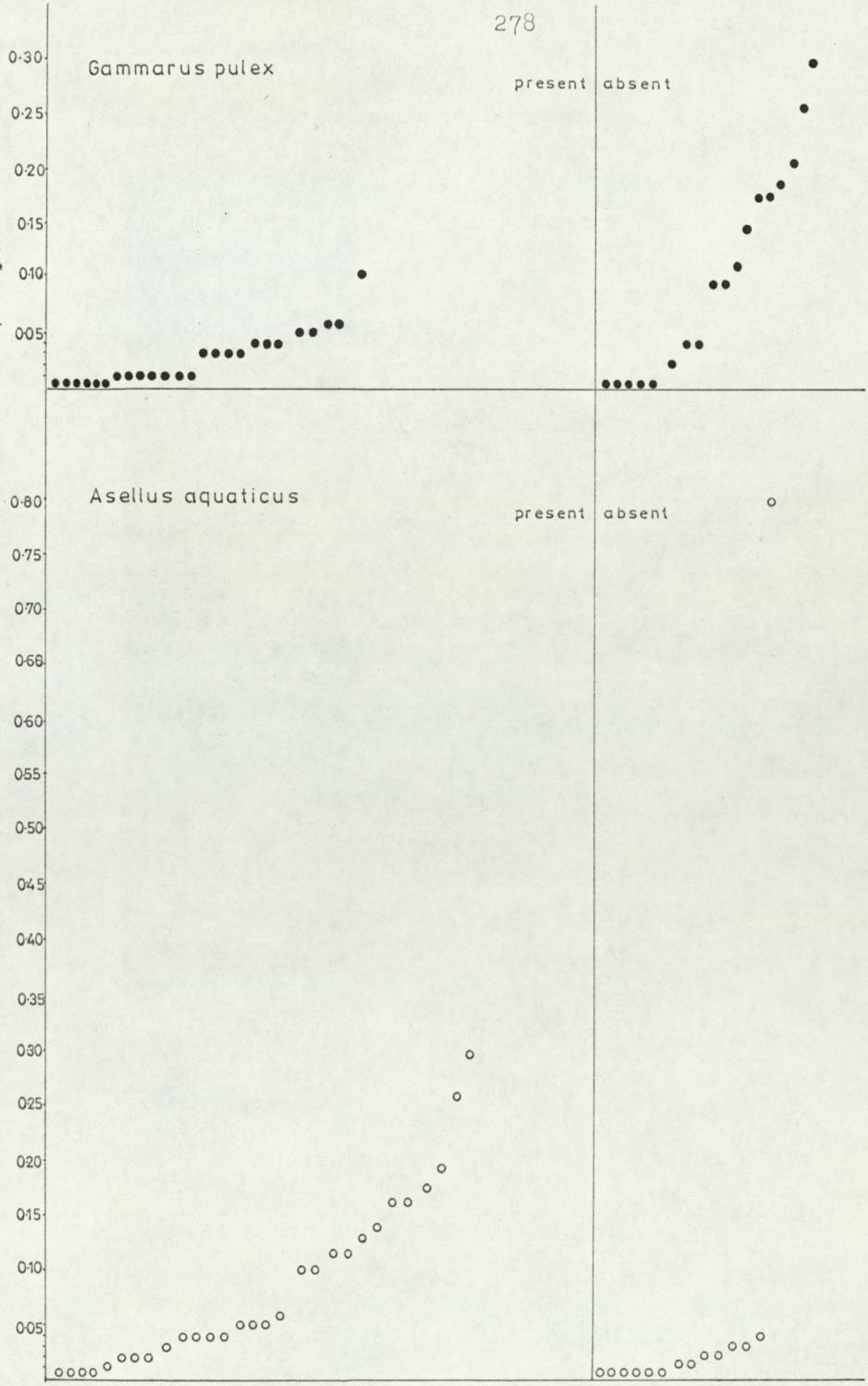

Fig.6.3. Occurrence of Gammarus pulex and Asellus aquaticus at various zinc concentrations in the Stour catchment

to the fact that, Asellus rarely occurs commonly in clean waters, possibly due to competition from Gammarus and other species. The absence of Gammarus below this level was probably because of pollution.

— evidence?

Too sweeping?

And what do you mean by commonly?

I think you are trying to make too much of the zinc / macro-invertebrate relationship without sufficient evidence.

7. An integrated approach to the disposal of waterborne wastes - a synthesis of ecological studies on percolating filters and receiving streams

Since the industrial revolution rivers and streams have been used increasingly for the removal of wastes from industrial processes and from the large residential areas which grew with industrialisation. As a result watercourses became grossly polluted in large urban areas and there were instances of disease recorded, such as the cholera epidemic in London. In response to this epidemic the piping and treatment of waste waters was implemented with the building of the Crossness sewage treatment works in the 1860's.

Apart from obvious physical processes, such as screening and sedimentation, the organic breakdown of waste products is essentially a biological or biochemical process. Most of the organic breakdown is, or should be, achieved at the works and the remainder finished in the receiving watercourse. Thus, man has utilized biological systems to treat and dispose of his waste. Ideally, there should be a minimum loading on the watercourse. However, the constraints of economics often impose a limit on the degree of organic breakdown in a works, but if the works has been designed properly, is run efficiently and is not overloaded, a high degree of purification is achieved and a minimal organic loading is imposed on the receiving stream.

In industrialised areas, such as the part of the Black Country studied here, the waste is often complicated by effluents from various industrial processes. The industry of the area was briefly discussed in section 2.1.3. (page 69) and the importance of metal-finishing industries was emphasized. The inclusion of these industrial effluents in the sewage can inhibit some of the breakdown processes, such as nitrification. Table 4.4 (page 204) shows the results of treatment at Freehold works, where the final effluent had a high ammonia content. One of the works studied, Roundhill works, also received a proportion of industrial waste. The effect of this waste was discussed in section 3.2.2. (page 129). A comparison was made with Gospel End works (section 3.3.1., page 143) and it was shown that twice the number of protozoan species were found at Gospel End as at Roundhill, though in the case of the latter, conditions were complicated by the mode of works operation. The effects of industrial discharges on stream fauna was discussed in section 4.2. (page 173) and it was shown that benthic macroinvertebrates were severely restricted by industrial effluents. Pollution of the watercourses in the area reduced their ability to complete the organic breakdown of sewage effluents. Although most of the works in the area, with the exception of Freehold, produced well-nitrified effluents, a higher organic loading was still imposed on watercourses which were, in some cases, already polluted. The toxic metals both in the watercourses and in some sewage works effluents imposed further limitations on the speed of organic breakdown and of recovery.

Where the works effluent was of high quality, however, such as at Gospel End after 1969, the effects on the receiving stream, Penn Brook, were less marked. Bacteria in the effluent enabled large populations of Simulium to develop, but Gammarus and Baetis were still found in appreciable numbers. Prior to the commissioning of the Roundhill works, the discharge from Roundhill Farm induced gross pollution in the river (page 209). Improvements in the discharge, subsequent to diversion and treatment of the sewage at the works, coincided with the amelioration of conditions in the river at station 59.

Thus, the nature of the sewage to be treated and the ecology of the receiving stream should be considered when designing a new treatment works. The design of the processes at the works should be regarded as facilitating the ecology of organic breakdown of the sewage. Also the uses to which the receiving stream is put should be given serious consideration, specially if it is used as a source of water supply. Unfortunately, most works have been designed in isolation to treat a stipulated flow with no more concern for the river than consideration of its fluctuations in flow. Works design has been regarded as an exercise in hydraulics in many cases, rather than providing the best conditions for maximum utilization of the breakdown potential of micro- and macro-organisms.

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