THE ECOLOGY OF ALGAE IN RELATION TO RIVER WATER QUALITY SURVEILLANCE

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The broad objectives of the work were to develop standard methods for the routine biological surveillance of river water quality, using the non-planktonic algae.

Studies on sampling methodology indicated that natural substrata should be sampled directly wherever possible, but for routine purposes, only a semi-quantitative approach was found to be feasible. Artificial substrata were considered to be useful for sample collection in deeper waters, and of three different types tested, Polythene strips were selected for further investigation essentially on grounds of practicality. These were tested in the deeper reaches of a wide range of river types and water qualities: 28 pool sites in 14 different rivers were studied over a period of 9 months. At each site, the assemblages developing on 3 strips following a 4, or less commonly, an 8 week immersion period were analysed quantitatively. Where possible, the natural substrata were also sampled semi-quantitatively at each site, and at a nearby riffle. The results of this survey were very fragmentary: many strips failed to yield useful data, and the results were often difficult to interpret, and of limited value for water quality surveillance purposes.

In one river, the Churnet, the natural substrata at 14 riffle sites were sampled semi-quantitatively on 14 occasions at intervals of 4 weeks. In this survey, the results were more readily interpreted in relation to water quality, and no special data processing was found to be necessary or helpful.

Further studies carried out on the filamentous green alga Cladophora showed that this alga may have some value as a bioaccumulation indicator for metals, and as a bioassay organism for the assessment of the algal growth promoting potential of natural river waters.

KEY WORDS: Algae, River, Water Quality, Biological Surveillance

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"Why does this magnificent applied science
which saves work and makes life easier
bring us so little happiness? The simple
answer runs: Because we have not yet
learned to make sensible use of it."

Albert Einstein
Address, California Institute of Technology,
February 1931.

1. INTRODUCTION

1.1 Water Quality: General Considerations

Water is a vital natural resource, a substance of fundamental significance in relation to the origin, evolution and maintenance of the ecosphere, and the relatively recent but rapid cultural evolution of man. The development of human society has been closely associated with the availability of water, both for direct consumption, and for various other purposes.

Odum (1971), whilst advocating the holistic approach to ecology, and considering the hydrologic cycle as an integral part of the ecosphere, recognised that the freshwaters alone have come to assume a remarkable degree of importance to man. Lotic systems in particular (Hynes, 1970), despite their relatively small total area, are responsible for the discharge of enormous volumes of water, and the drainage of a substantial proportion of the terrestrial surfaces occupied by man. These systems have long been influenced both quantitatively and qualitatively as a result of human activity, indirectly through land use, and directly in their role as sources of water for consumption and use, as well as convenient disposal systems.

Concern for water quality has arisen from the general increase in ecological awareness exhibited by mid-twentieth century man. Water quality is however very difficult to define absolutely, and it has been generally agreed (Warren, 1971; Hawkes, 1974; Hellawell, 1978) that it should be defined pragmatically in

relation to actual or potential legitimate use. This implies that water quality, in relation to a particular use, may be defined in terms of certain criteria and standards for that use, and further that different sets of criteria and standards may be associated with different legitimate uses. In this way, water of high quality for one use may be regarded as of lower quality for another purpose.

The legitimate, but in some cases potentially conflicting uses of river water (Klein, 1962) include abstraction (for potable domestic supply and a variety of industrial and agricultural purposes), as well as fisheries, navigation, recreation, general amenity and, justifiably, the discharge of effluents. It should further be noted that the Water Authorities are expected to recognise the importance of preserving natural beauty, and of conserving the aquatic flora and fauna (Water Act, 1973).

Water pollution may now be defined as any factor which so changes the characteristics of the water that any of its legitimate uses are impaired. Again, it must be recognised that water considered to be polluted in relation to any one use may nevertheless be regarded as satisfactory for some other purpose. River pollution is an ancient problem, which may take place as a result of factors not necessarily associated with the activities of man, but the problem as it exists at present in Britain is essentially the direct result of human activity, and may be said to date from the early nineteenth century, with the consolidation of the Industrial Revolution (Hynes, 1960; Klein, 1962; Warren, 1971). The change from an agrarian basis of civilization, which had lasted from neolithic times, to an industrial basis depending

even for cultivation largely on fossil - fuel energy (Egerton, 1957), coupled with an associated increase in human populations, resulted in profound and continuing ecological disturbance. Although sewage, industrial and agricultural discharges remain the most important causes of river pollution, the problem is a changing one, reflecting the nature of the society and activities that are responsible for it. Hawkes (1968) found it convenient to classify different types of pollution, not according to source, but to the ecological factors most affected (Table 1.1). As is the case with many such classification systems, the distinctions between different factors may be difficult to define or essentially arbitrary, and in reality, most cases of pollution involve the interaction of several of the factors mentioned.

In practice, the majority of river waters are required for a variety of uses, and their quality in relation to these several uses must be considered. Generally, the upland nutrient-poor (oligotrophic) waters would appear to be the most satisfactory for multiple use, and it has become common to regard such waters as of higher quality than the nutrient-rich (eutrophic) lowland waters. By definition, increasing pollution would tend progressively to lower the quality of any of these waters, rendering them suitable for fewer uses, or necessitating more rigorous treatment before use or re-use.

Clearly, society must develop sound policies and an administrative system for the management of its water resources. It has been suggested (Hawkes, 1962, 1974; Warren, 1971) that the initial determination of objectives should involve the

TABLE 1.1 A classification of types of pollution according to the ecological factors most affected (modified from Hawkes, 1968).

1. Physical	(a)	Changes in the physical properties of the water: temperature suspended solids colour surface properties radioactivity
	(b)	Changes in the physical properties of the substratum: silting organic growths
2. Chemical		Changes in the chemical properties of the water: deoxygenation toxicity pH salinity
3. Nutritional		Quantitative or qualitative changes in the nutrient status of the water: organic enrichment inorganic enrichment (eutrophication)

classification of rivers according to the uses by which each might best serve the human community. It would then be necessary to select those criteria by which water quality would be assessed in relation to the objectives decided, and finally to set standards for the criteria selected in order that the objectives might be achieved. This is a complex process, demanding the integration of social, political, economic, scientific and technological considerations. One interesting and flexible multidimensional approach, developed in this country, is the Quality State concept (Newsome, 1972). This forms the basis of a dynamic economic model of the polluted river Trent system (Collinge et al., 1970), in which river water quality is described comprehensively in terms of ordered sets of significant ranges of water quality parameters, together with their associated economic functions.

In the assessment of water quality, complete analysis for all the relevant parameters is usually not practical. Hawkes (1974) distinguished between two types of assessment: the specific investigation (carried out to assess the quality of a given water for a specific purpose, or to assess the effect of a specific discharge), and the general routine survey of a river system, to assess its general pollution condition. In either case, the water quality criteria selected would be determined by the objectives of the investigation. Largely for historical reasons, the most commonly employed criteria in routine work are physico-chemical, but would appear to be related to the assessment of the effects of the most common type of discharge, the sewage works effluent, especially in relation to fisheries interests. Thus,

most of the analyses carried out on a routine basis by the Water Authorities (Table 1.2) are directly or indirectly related to the oxygen content and deoxygenation potential of the water, its solids content, toxicity and degree of eutrophication.

The desire to protect fisheries requirements has been beneficial generally, since waters capable of supporting healthy fish populations tend also to be of high quality for other legitimate uses.

1.2 Water Quality: Biological Considerations

Ecosystems are capable of self-maintenance and self-regulation, as are their component populations and organisms (Odum, 1971). The homeostatic properties of aquatic ecosystems are essential not only in the maintenance of the natural characteristics of water resources, but also the self-purification of polluted waters (Hynes, 1960) and indeed the controlled treatment of used waters (Curds and Hawkes, 1975).

Apart from their natural functional significance in ecosystem homeostasis, the presence of organisms in water may be of applied significance (Hawkes, 1974) in that they may be pathogenic, economically important by being of benefit or by causing nuisance, or in some other way indicative of water quality.

1.2.1 Pathogenic organisms

Many organisms of enteric origin, including some pathogens,

TABLE 1.2 List of water analyses commonly carried out in routine surveys by Water Authorities (from Hawkes, 1974).

Temperature	Albuminoid/organic nitrogen
Suspended Solids (S.S.)	Ammoniacal nitrogen
Transparency	Nitrite nitrogen
Electrical Conductivity (as $S\,cm^{-1}$ at 25 °C)	Nitrate nitrogen
	Phosphate
Chlorides	Sulphate
Alkalinity (as $CaCO_3$)	Metals
Hardness (Ca, Mg)	cadmium
pH	chromium
Dissolved oxygen	copper
Biochemical Oxygen Demand (BOD 5d 20 °C)	nickel
	zinc
Permanganate value (PV 4h 27 °C)	Phenols
	Cyanides
Dichromate value (COD)	Oils
	Detergents (as Manoxol O.T.)

enter rivers via sewage works effluents. Although in Britain the precise aetiological significance of these organisms is difficult to establish, the potential dangers are evaluated on a routine basis by means of simple but well developed quantitative bacteriological techniques (Department of Health and Social Security, 1969). In practice, water is examined not for the presence of the pathogens themselves, but for the presence of other micro-organisms known to be indicative of faecal contamination, most commonly the coliform group and particularly Escherichia coli. Waterborne pathogens of non-faecal origin, and those affecting economically important organisms such as fish and farm animals are of less general concern in Britain, and tend to be sought specifically only when their presence is suspected to be significant.

1.2.2 Organisms of economic significance

It has already been noted that the desire to maintain inland fisheries has been greatly influential in the development of water pollution assessment strategy in Britain. Other groups of organisms, particularly micro-organisms, are of economic significance in that they may create nuisance.

Excessive algal development, frequently associated with eutrophic conditions in both lentic and lotic waters (Downing, 1970) is considered to be deleterious, especially in relation to potable water supply, fisheries interests and recreation and amenity value. The development of blooms of suspended algae in lakes, reservoirs and slow flowing rivers used as sources of

potable water may cause the well-known treatment and distribution problems of filter blockage, tastes, odours and turbidity in the finished water, and supply main infestation by invertebrate animals. Fish mortalities may occur as a result of elevation of pH values during periods of rapid photosynthesis, or deoxygenation as a result of algal respiratory demand or decomposition. It is reported (Gorham, 1964; Schwimmer and Schwimmer, 1964, 1968; Heaney, 1971) that certain algae, notably planktonic Cyanophyta, may in large numbers be toxic to a wide range of animals, including fish, farm animals, birds and man. Prymnesium parvum (Haptophyta) is known to produce an exotoxin responsible for dramatic fish kills in various parts of the world (Bowler, 1971; Holdway et al., 1978). Excessive growths of macroalgae such as Cladophora (Section 6) and other macrophytes (Robson, 1973) may also adversely affect fisheries, angling activity, navigation, recreation and amenity in all types of aquatic habitat, whilst the development of sewage fungus (Curtis, 1969) may similarly create nuisance in rivers.

1.2.3 Biological indicators

Biological change, appropriately described and interpreted, has often been found to be indicative of environmental change. Attempts have therefore been made to utilize biological information in the assessment of water quality and the detection of pollution (Hawkes, 1962, 1974, 1979; Warren, 1971; Wilhm, 1975; Hellawell, 1978). In this particular application of the biological indicator concept, as Warren (1971) was careful to point out, it is important to recognise the distinction between ecological change in general,

and that which is actually taken to be significant in relation to water quality and pollution, as defined independently in terms of legitimate use. It should be remembered that spatial and temporal changes are a natural feature of all aquatic ecosystems, for example the longitudinal zonation frequently exhibited by rivers (Hawkes, 1975), and the pattern of seasonal change characteristic of virtually all types of habitat. Furthermore, some ecological change, even if apparently induced by human activity, may nevertheless be accepted as compatible with desired legitimate use. It follows then that not all biological change is necessarily indicative of water quality change.

Many approaches to the application of the biological indicator concept to water management, encompassing virtually all the major aquatic taxa and every level and aspect of biological organisation and response have been developed.

Biological response, usually at the organism or population level, is utilized directly in laboratory bioassays (Martin, 1973) to assess the ecological impact of environmental change. The organisms employed for bioassay purposes are frequently of economic importance themselves, but results are usually taken to be of broad ecological significance. Considerable effort has been expended in the development of fish toxicity tests and algal growth enhancement tests, and the approach has inevitably been diversified to make use of a wide range of taxa and different types of response. The most serious problem in this type of work, as with autecological work in general, is the interpretation of data in relation to the complexity of the field situation. For

this reason, studies involving modified or simulated natural systems (Warren and Davis, 1971; Huddart, 1978; Lund, 1978) are likely to yield information of fundamental importance. A further, specialised, application of the bioassay approach is the use of specific, well-defined biological responses at the organism level to detect environmental change in the field, for example the use of captive fish to provide a rapid early warning of environmental deterioration (Price, 1978).

Many aquatic organisms are able to accumulate substances from the aqueous environment in their organs or tissues. This natural process is of potential indicator value in that substances of environmental interest, such as metals, radioactive isotopes and synthetic organics, which may be present in water only intermittently or at low concentrations, may be detected and evaluated more readily by tissue analysis of the appropriate organisms. This is a rapidly expanding field in which many difficulties are apparent; little is generally known, for example, of the biochemical processes involved, the rate of accumulation and possible breakdown or loss of substances, and the correlation between accumulated and environmental levels at different localities and under different physico-chemical conditions. Only continuing research is likely to result in the emergence of reliable and easily interpreted procedures.

It has long been recognised that different communities of aquatic organisms tend to become established in waters of different quality (Hawkes, 1974). On this premise it has been suggested that biological information, derived from the analysis of aquatic communities, may be of value in the assessment of

water quality and the detection of pollution. The following list, modified from Hawkes (1978) identifies the principal changes of indicator value that have been shown to occur, often simultaneously, in aquatic communities in response to changes in water quality:

a) appearance or disappearance of particular taxa
b) change in total numbers of taxa
c) change in quantitative importance of taxa
d) change in proportional quantitative importance of taxa

These essentially structural changes might also be expected to influence the functional properties of the community, for example its productive and trophic characteristics. Many attempts have been made to exploit one or more of these changes in the assessment of water quality and the detection of pollution; most workers have inevitably tended to specialise in, and therefore to advocate particular groups of organisms. In this way, virtually all the major aquatic groups - bacteria, algae, fungi, protozoa, macrophytes, invertebrates and fish - have been involved in this type of work.

Although 'biological surveillance' may involve any or all of the approaches outlined in this section, the term is most commonly employed to refer to the detection of significant field changes in community composition and structure, and unless otherwise stated, this is the usage adopted in this thesis.

1.2.4 Biological surveillance of rivers

"Surveillance" may be defined as the standardised measurement of chosen variables at different stations, with sufficient frequency and over a sufficiently long period of time to allow spatial and temporal comparisons to be made, and significant change to be detected. In some cases, either the spatial or the temporal element may be eliminated, that is, a single station may be surveyed in time without reference to other stations, or a series of stations may be surveyed at virtually the same time but not repeatedly. Hellawell (1978) further defined "monitoring" as surveillance undertaken to ensure that previously formulated standards are being met.

Clearly, the information derived from physico - chemical surveillance is determined and limited in advance by the choice of analyses to be performed, and it is usually not possible or practical, especially on a routine basis, to determine the entire range of parameters of potential interest in relation to water quality. Furthermore, the physico-chemical parameters of river waters may vary widely, and particularly in the case of intermittent or erratic discharges, discontinuously. Thus the analysis of discrete water samples taken at intervals from a station is likely to yield only an incomplete, transient and even misleading assessment of water quality at that station. Continuous assessment would obviate some of these difficulties, but again technical, practical and economic considerations severely restrict this approach. Finally, it should be noted that solid material accumulating on the stream bed might remain undetected by the analysis of water samples alone.

In addition to the intrinsic value of certain types of biological information, the advantage in using the biota for water quality surveillance in the field (Hellawell, 1978) derives from their prolonged exposure and integrated response to varying environmental conditions. Thus the prime objective of biological surveillance is the detection and measurement of the effects of otherwise unknown or intermittent discharges, or of other environmental changes, whether beneficial or adverse, which arise through changes in water management policy. On detecting a significant change it is necessary to identify the causative agent and, if necessary, attempt to ameliorate its effects. Continued surveillance provides useful evidence of the effectiveness of such action and may be of practical value, for example in assessing the opportune time for restocking following a severe fish-kill. Another important objective of biological surveillance is the rapid assessment of general water quality for the large-scale appraisal and broad classification of water resources; again, advantage is taken of the integrated response of the biota to the overall impact of physical and chemical factors during the period prior to sampling, in contrast to the limited information derived from a physico-chemical survey alone. Finally, retrospective studies of the ecological consequences of known changes in environmental conditions may actually prove valuable in the establishment of water quality criteria for future water management procedures.

In flowing waters, "sedentary" organisms with relatively long life-cycles are most likely to reflect the quality of the water that has flowed over them in the past, and allow the most

valuable spatial and temporal comparisons to be made. For large-scale spatial comparisons, it is clearly desirable to employ the more commonly encountered and widely distributed taxa. Further important considerations are the practicality and reliability of sample collection and analysis, including the identification and quantitative evaluation of taxa, the description and interpretation of surveillance data and the presentation of results. Not only is it desirable, as far as possible, to recognise and define the significance of these data in relation to water quality, but some degree of data reduction or condensation is often considered to be expedient, and particularly in the case of large scale surveys, findings may be summarised concisely in the form of simple classes, grades, indexes or scores. In this way, large masses of data are rendered more readily manageable and more easily comprehensible, especially to non-biologists, and information of known indicator value may actually be emphasised. The success of any surveillance programme will therefore depend upon the suitability of the organisms chosen, the method and frequency of sampling and the ecological validity of the analytical procedures employed.

Hellawell (1978) discussed the advantages and disadvantages of the different aquatic groups for river surveillance purposes. Most workers have used or recommended the benthic macroinvertebrates for both routine and specific surveys, and indeed several biotic indexes are based on their occurrence (Hawkes, 1974, 1978). Other groups, particularly the non-planktonic algae, have been strongly advocated, but apart from their importance as potential nuisance organisms, have failed to

achieve the popularity of the invertebrates as a first choice for water quality surveillance.

In the ultimate defence of biological surveillance, however, it is necessary to draw attention to its limitations (Hawkes, 1974, 1978). Although biological surveillance identifies biological change which may be indicative of water quality change, it does not identify the specific cause of this change. Careful and informed interpretation of biological data may suggest the cause, but confirmation must be achieved subsequently by means of further investigation involving physico-chemical analyses. Some biological data are of course directly relevant in the consideration of conservation and water quality, but a major difficulty is the interpretation of biological data in relation to the entire range of different legitimate uses of water, and the associated water quality criteria. Certainly, a good general correlation may exist between water quality, as assessed by biological means, and its suitability for multiple use, but it should be remembered that not all biological change is necessarily indicative of water quality change, and further that certain water quality changes may not be detected, or even be amenable to detection, by biological surveillance alone. Ideally, biological surveillance should involve as wide a range of taxa as possible, and the data should be interpreted by trained biologists, but in practice surveillance tends to be less comprehensive and the need to simplify data inevitably results in loss and possibly distortion of information, and may lead to undesirable rigidity of thought and even misunderstanding. In conclusion, it should be emphasised that

biological and physico-chemical data are both essential, yielding different but complementary types of information.

2. THE RESEARCH PROGRAMME

2.1 Objectives and Execution

The work presented in this thesis was completed as part of a three year research programme initiated and supported by the Water Data Unit (Department of the Environment), and carried out during the period January 1976 to December 1978, in the Applied Hydrobiology Section (Department of Biological Sciences) of the University of Aston in Birmingham. The objectives of the programme, as stated in the research contract DRG/480/100, were:

> 'to develop and evaluate a standard biological method for the surveillance of river water quality, and to devise a method of processing the surveillance data'.

The principles and practice of river biological surveillance have already been considered in Section 1. It is now generally agreed that the assemblages of organisms associated with the river bed, or with other submerged substrata, are the most suitable for biological surveillance purposes. In practice it is desirable, and indeed often possible, to select physically comparable sampling stations. In the upstream reaches, 'riffles' - shallow stretches with the water flowing rapidly over a predominantly stony substratum - are popular sampling sites. In the deeper lowland reaches, however, riffles are less common, and such reaches present difficulties in the practical application of biological surveillance for several reasons:

a) The absence of riffles as standard sampling sites precludes comparison with upstream stations.

b) Direct sampling is usually difficult and may be dangerous.

c) The benthic assemblages are less well known and tend to be less well developed than in riffles.

The objectives of the research programme were formulated with the intention of overcoming these difficulties, by establishing the appropriate sampling and data processing methods. The possibility of using artificial substrata as standard sampling units was thought to merit particular attention.

Two research students were appointed; one (C. Girton) to work on the benthic macroinvertebrates, and the present author to work on the benthic algae (see Section 2.2). Since the role of the algae for biological surveillance purposes appeared to be less clearly established than it is for the invertebrates, it was considered particularly important to review and evaluate critically the relevant literature (Section 3). The field work was planned in two phases, corresponding to the first two years of the research programme, as follows:

Phase 1 (1976) - Preliminary studies to select suitable sampling methods for routine surveillance work (Section 4.).

Phase 2 (1977) - River survey work to evaluate the methods selected in Phase 1 in a wide range of river types and water qualities (Section 5.).

It was decided that the third year (1978) should be left open to pursue more freely any relevant line of investigation, not necessarily directly related to the original research contract. This time was devoted to various studies on the filamentous green alga Cladophora (Section 6.). Finally, an attempt was made to formulate general conclusions and recommendations based on the findings of the programme (Section 7.).

2.2 Scope, Definitions and Terminology

The freshwater algae may be classified broadly according to habitat: those found floating freely in open water (the plankton) and those found attached to, or closely associated with, submerged substrata such as sediments, stones, rocks, macrophytes and artificial objects. Artificial objects would include not only a variety of articles discarded as waste, and functional structures such as buoys and piles, but also those artificial substrata positioned deliberately for purposes of sampling (Section 3.1.2).

The non-planktonic algae are themselves frequently found growing in close association with a range of other taxa, particularly bacteria, fungi, protozoa and microinvertebrates such as rotifers and nematodes. As might be expected, the

composition and degree of development of these assemblages varies considerably in response to a range of physical, chemical and biological factors (Section 3.2.1). The majority of the organisms involved are microscopic, but they frequently aggregate to form macroscopically visible growths, ranging in gross morphology from closely applied thin layers, to flocculent attached coatings. Moreover, several of the common algal genera typically form even larger structures: conspicuous growth mats or cushions, or multicellular, often filamentous thalli capable of covering large areas of the bed, and themselves forming substrata for colonisation by the smaller forms.

The somewhat confusing terminology that has arisen to describe, define and classify these heterogeneous non-planktonic assemblages has been reviewed by Cooke (1956), Sladeckova (1962), Wetzel (1964) and Hutchinson (1967). In all aquatic habitats, the organisms associated with the solid-liquid interfaces at the bed or bottom are considered to form the benthic community, or benthos. In the strict sense, this would include only those forms associated with sediments, stones and rocks, but not those associated with macrophytes and artificial objects. The terms 'Aufwuchs' and 'periphyton' are frequently encountered in the literature, but unfortunately, detailed definitions of both these terms have varied considerably and this has resulted in some confusion. Both terms have been employed in a relatively restricted sense, to refer only to those organisms attached to or closely associated with submerged solid surfaces projecting above the bed, particularly macrophytes and artificial objects.

In this way, a distinction is retained between the Aufwuchs or periphyton and the true benthos. Many authorities however have preferred to adopt broader definitions of the Aufwuchs or periphyton, including all organisms, except rooted macrophytes, attached to or closely associated with submerged substrata of all types. The British phycologist Round (1964) has suggested that the algal component should be regarded simply as one phase of a broadly defined benthos. It would then become possible to indicate, by means of a more specific terminology, the type of substratum under consideration. In this way, the epipelic algae are associated with fine sediments (muds and silts), the epipsammic algae with sands, the epilithic algae with all types of stony and rock substrata, and the epiphytic algae with larger plants. Presumably, this same terminology could also be applied to other taxonomic groups, as well as to the taxonomically more inclusive terms themselves; thus Wetzel (1964) and Wetzel and Westlake (1974) have recommended that the appropriate qualifying adjective - epipelic, epipsammic, epilithic or epiphytic - should be employed to precede the general term periphyton. One shortcoming of this scheme is that no term seems to exist for those assemblages of organisms associated with artificial objects, although in most instances the origin of such assemblages is of course contextually clear.

The occurrence of planktonic algae in streams and rivers has been reviewed in some detail by Hynes (1970). Whilst true planktonic species occur typically in lentic waters, river plankton tends to be adventitious, being derived from contiguous lentic systems or from the bed in shallower parts of the river or

its tributaries. The larger, slow flowing rivers may however support a well developed, viable and reproducing plankton consisting of true planktonic forms as well as those derived from the benthos. As explained in Section 1, the presence of large numbers of suspended algae, particularly in eutrophic lowland rivers used as sources of potable water, may be of direct economic importance. Conversely, the river plankton may in some cases provide a useful indication of trophic conditions; Whitton (1979) cites the long-term changes that have occurred in the composition of the plankton of the river Thames, which may be attributable to eutrophication, and Williams (1964, 1972) has used planktonic diatom diversity as a trophic index to compare different river stations in the United States. In general, however, the river plankton is not considered to be particularly suitable for biological surveillance purposes, both on conceptual grounds (the plankton can only 'indicate' the past history of the water in which it is contained) and in any case because of the preponderating influence of factors other than water quality, such as local conditions, seasonal changes and the incidence of spates. These problems are apparent, for example, in the surveys carried out by Backhaus and Kemball (1978), Klose (1968), Staub et al., (1970), Villegas and de Giner (1973) and Wager and Schumacher (1970).

For the purposes of the research programme, only the benthic algae, and those algae associated with artificial substrata, were considered. The only major exception to this general statement was that the predominantly heterotrophic 'sewage fungus' community of the benthos (Section 3.2.1) was also considered where appropriate.

3. LITERATURE REVIEW

3.1 The Collection, Treatment and Analysis of Samples

Hellawell (1978) has presented a general discussion of the factors influencing the choice of sampling strategy (i.e. the number and location of sampling stations, and the time and frequency of sampling) in any river biological surveillance programme. In practice, the sampling strategy finally adopted is likely to represent a compromise between the objectives of the programme, and the limitations imposed by practical and economic considerations. Within this general framework, the methods actually employed for the collection, treatment and analysis of samples are clearly of fundamental importance, and are determined largely by the biological and ecological characteristics of the groups chosen for study, and by the data requirements of the programme itself, in particular the degree of taxonomic precision and quantitative accuracy desired.

Methods for the collection, treatment and analysis of samples of non-planktonic freshwater algae have been reviewed in some detail by Lund and Talling (1957) and by Sladeckova (1962), whilst further useful information has been presented by Cooke (1956), Blum (1960), Lund (1961), Hohn (1966), Hynes (1960, 1970), Vollenweider (1974), Wetzel (1975), Whitton (1975, 1979) Hellawell (1978), and Jones (1979). In general, it is usual for all samples collected in the field to be transported to the laboratory (in containers suitable to prevent desiccation or damage) before

further treatment or analysis is attempted. For biological surveillance purposes, the objectives of this further procedure are usually to identify the organisms, and to estimate their quantitative importance.

Samples collected in the field may vary considerably in character; in some cases, the organisms are removed directly from their substratum in the field, and are then usually suspended in a small quantity of water for further work, but in other cases it is more convenient to collect quantities of the substratum material itself (e.g. sediments, stones, macrophytes or artificial substrata) and to subject these either to direct microscopic examination, or to some other form of treatment to remove the organisms, again usually to aqueous suspension, before further work is carried out. For quantitative work, it is clearly important that these procedures are quantitatively controlled. In the following account, Sections 3.1.1 (Natural Substrata) and 3.1.2 (Artificial Substrata) deal with the field and laboratory procedures leading up to the final stages of identification and quantitative evaluation, which are themselves discussed in more detail in Section 3.1.3 (Sample Analysis). In this final section, the overall design of quantitative procedures is also considered.

It should be remembered that many of these procedures were developed originally for use in lentic rather than lotic habitats, but at the same time the general principles involved are usually of greater importance than the detailed design and construction of apparatus, and most methods are readily adapted for river work.

3.1.1 Natural Substrata

A number of methods have been developed for the collection of samples directly from all types of submerged natural substrata. In shallow waters, these substrata are usually readily accessible, but in deeper waters this may not be the case. It may then become necessary either to dive (Wood, 1963) or to employ grabs, corers, dredges or similar devices (Hellawell, 1978) for the collection of adequate samples. Few attempts have actually been made to collect samples from deep rivers by these means, partly because of the practical difficulties involved, and partly because such rivers would not be expected to support a particularly well developed bottom flora, especially where the bed is physically unstable and light penetration poor. For these reasons, it is usually more convenient and profitable to sample directly in the shallower water close to the banks (e.g. Moore, 1976), or to use artificial substrata (Section 3.1.2).

Should it be required only to produce qualitative data (i.e. a species list) for a particular site, then no special or elaborate apparatus is required (Sladeckova, 1962). Samples may be removed directly from their substrata in the field (knives, scrapers and similar implements have been variously modified for this purpose), or samples of the actual substrata (sediments, stones and macrophytes) may themselves be removed by the most convenient method, and transported to the laboratory for subsequent treatment and examination. Clearly, the main requirement for this type of work is that all the taxa present at a site should in fact be collected. The optimum number of

samples required for a species list will depend on the diversity and dispersion of the flora, and is most easily estimated from the cumulative number of species taken by successive sampling in all the microhabitats present within the area of interest (Hellawell, 1978).

The collection of samples for quantitative work tends to be more difficult, mainly because of the very variable size and morphology of the organisms involved, and their often extremely heterogeneous spatial distribution (Wetzel, 1975; Whitton, 1975). At any one sampling site, several different substratum types may be present, and the taxonomic composition and standing crop of the associated assemblages may vary widely over very short distances. The theoretical basis of practically all quantitative techniques for the collection of samples (including the use of artificial substrata) is the complete removal of all organisms from a known area or quantity of substratum. The reliability of estimates of absolute mean population densities within a habitat depends on the number, location and size of sample replicates, and on the number and size of any further subsamples taken during subsequent laboratory analysis. These considerations are discussed in greater detail in Section 3.1.3.

3.1.1.1 Epipelic and epipsammic algae

The epipelic algal flora, associated with submerged sediments such as muds and silts, tends in flowing waters to be composed predominantly of diatoms, blue-greens, coccoid Chlorophyceae and euglenoid flagellates (Round, 1973). Owing

to the particle size and physical instability of most sedimentary substrata, it is usually difficult to collect relatively pure samples of epipelic organisms directly in the field; it therefore becomes necessary to collect samples of sediment, containing the organisms, for subsequent laboratory treatment and examination. Methods for the estimation of numbers and pigment content in epipelic algal assemblages have been reviewed and critically evaluated by Eaton and Moss (1966). In shallow waters, sample collection is most effectively achieved by means of some form of simple suction apparatus. Lund (1942) used an inverted thistle funnel which could be lowered on to the sediment surface; surface material could then be sucked by means of a hand pump through a connecting tube into a collecting bottle. Round (1953) employed a long glass tube, held vertically and stoppered by a finger at the upper end, the other end then being lowered on to the sediment surface. A sample of surface material could be collected in the tube by simultaneously releasing the finger and drawing the lower end of the tube across the sediment surface. In both these methods, the actual area of sediment surface sampled is difficult to control or determine, and strict quantitative work is therefore not possible. Eaton and Moss (1966), and later Hickman (1969), overcame this problem by isolating a known area of sediment surface within a Perspex cylinder. The surface material enclosed by the cylinder could then be collected, again by suction, through tubing into a plastic collecting bottle previously compressed by hand to expel air. In deeper waters, it becomes necessary either to dive or to employ mechanical core samplers, the main requirement being to avoid disturbance of the core surface. In this respect, the Jenkin and Kullenberg core

samplers are probably the most suitable (Lund and Talling, 1957; Hellawell, 1978) and only the uppermost layers of the cores need be retained for treatment and examination.

Clearly, samples collected by these methods are likely to contain water and a high proportion of extraneous solid material, consisting mostly of sediment particles of much the same order of size as the epipelic organisms themselves. Such samples can be examined directly for the presence of epipelic organisms, but this tends to be difficult, owing to the obscuring effect of the sediment particles, especially where flocculent organic matter or fine silt are abundant (Eaton and Moss, 1966). These authors further pointed out that dilution of the sample to reduce this interference also results in an undesirable reduction in algal density, rendering subsequent quantitative work difficult. Lund (1942) developed a technique for the concentration of positively phototactic forms in the laboratory by leaving sediment samples for some hours in dishes blackened except for a small area facing the light, towards which the organisms would migrate. The same author (Lund, 1945) also found that the algae of damp soils would move on to the undersides of coverglasses placed on the soil surface, and this technique was subsequently adopted by Round (1953) for the recovery of epipelic algae from sediment samples taken from freshwater habitats. Eaton and Moss (1966) found that a double layer of lens tissue was more effective than coverglasses in the application of this technique.

It is now known that many freshwater epipelic algal associations exhibit persistent diurnal vertical migration rhythms (Round and

Happey, 1965; Fischer et al., 1977), resulting in a peak in cell numbers at the sediment surface at approximately the same time each day. This means that the time of harvesting in the procedures described above may be critical, and indeed the method developed by Eaton and Moss (1966) takes this into account.

The true epipsammic flora has not been extensively investigated, but appears to consist of small forms, mainly diatoms, attached more or less firmly to the surfaces of sand particles (Round, 1965). Methods for the examination of this flora have been evaluated and compared with those employed for epipelic assemblages by Moss and Round (1967). The most effective method is simply to wash the sediment sample, obtained as described above, repeatedly in water to remove all extraneous material, leaving only sand particles together with the attached epipsammic organisms. Subsamples may then be taken for direct microscopic examination, or the algae may be detached by ultrasonic vibration.

3.1.1.2 Epilithic algae

Epilithic algae are encountered on a variety of substratum types, ranging from relatively fine gravels, through stones and boulders of variable size, to extensive bedrock. No one sampling method is suitable for all these substratum types, although for quantitative work the objective is almost always the complete removal of all the algae from a known area.

Gravels and small stones in shallower waters may be

removed directly by hand from an area delimited by some form of quadrat or cylinder. Marker (1976a) employed a Perspex ring weighted with lead to hold it firmly in the stream bed. When in position, the ring was observed from above by means of an open wooden box with a transparent Perspex base, pressed below the water surface. The gravel and stones enclosed by the ring were then removed by hand and placed in a small tray attached to the viewing box. Again in deeper waters it becomes necessary either to dive or to employ a suitable grab, corer or dredge (Hellawell, 1978). Depending upon the size of the gravel particles or stones in these samples, the algae may be detached by ultrasonic vibration, vigorous shaking in water, or by scraping or brushing.

In the case of larger stones, boulders and bedrock, it becomes feasible to remove the algae from known areas of single stones or stone surfaces. Most workers have employed some form of open-ended box or cylinder of known area of cross section; such a device can be pressed against the surface to be sampled and the algae thus isolated within it scraped or brushed free and washed or pipetted into a collecting bottle. Young (1945) employed an instrument of square cross section, Gumtow (1955) a brass ring, and Douglas (1958) a cylinder, constructed by removing the base from a polyethylene bottle. Similar methods have been used more recently by Klotz et al. (1976) and Olive and Price (1978). Ertl (1971) designed a device for use on rough substrata, consisting of a sampling cylinder of known area of cross section inserted and fixed concentrically within an outer cylinder of substantially greater diameter. The free

space between the two cylinders is filled with Plasticine, which can be forced down on to the substratum in order to isolate the sampling area more effectively. A more elaborate device has been described by Gale (1975). This consists of a modified bar clamp fitted with a specially constructed collecting cup, incorporating an acrylic ring to delimit the sampling area and a replaceable neoprene foam collar to accommodate surface irregularities. In the field, a suitable stone is clamped into the apparatus in such a way that the mouth of the collecting cup comes to rest and is held firmly against the surface to be sampled. This operation can be carried out, if necessary by divers in deep water, before removing the stone completely from the water. Thus a known area of stone surface, together with a small volume of overlying water, is trapped within the sampling cup. In the laboratory, two cleaning ports in the cup body are opened, allowing access to the sample area, which can then be scraped and brushed clean, the detached material being removed by pipette or flushed out through an overflow pipe into a collecting bottle. The author also recommended the use of a rapidly vibrating dental cleaning instrument for more efficient removal of the attached organisms.

The methods described so far are most readily used on stones that can be removed from the water; larger stones, boulders and bedrock must usually be sampled whilst still submerged. The method developed by Douglas (1958) and used later by Descy (1976a) to sample permanently submerged rock surfaces is in principle similar to the other methods, involving the use of a brush within a sampling cylinder. Because this device must

remain under water, however, the tubular handle of the brush is itself connected by further tubing to a collecting bottle, into which the algae detached from the sample area may then be drawn by suction. Neel (1968) employed a less elaborate device, consisting of a rectangular brass frame fitted with a collecting bag made of bolting cloth. Material scraped from the area delimited by the frame under water was carried into the bag by the water current.

A number of problems are associated with the removal of epilithic algae by scraping or brushing; some forms may resist detachment, or are lost, damaged or destroyed, and it is likely that the sample will contain quantities of extraneous material. Margalef (1949) devised an ingenious method for stripping the algae directly from stone surfaces. The algal layer, still attached to the stone or rock fragment, is first fixed, stained and dehydrated, and then a collodion solution is poured over it. When dry, the collodion film, together with the algal layer, may be peeled away from the stone surface and mounted for direct microscopic examination. As Hynes (1970) pointed out, this technique does not appear to have been used extensively, even by its originator, although Cattaneo (1978) has described a modified version, involving the use of a cosmetic face mask for the removal of algal layers directly from the surfaces of natural and artificial macrophytes.

A method for the observation and enumeration of epilithic algae directly on stone surfaces, involving the use of incident light fluorescence microscopy, has been developed by Jones (1974).

Although this technique has been used subsequently by the same author (Jones, 1978) to study diatom populations in a small stony stream, it has perhaps not been sufficiently widely tested to allow an assessment of its suitability for more general use.

3.1.1.3 Macroscopic forms

Several of the common epilithic algae, and sewage fungus, typically form conspicuous macroscopic growths covering relatively large areas of the bed, and a number of methods have been developed for the quantitative assessment of these forms. It is often quite satisfactory to make an essentially subjective assessment of percentage cover, as reported for example by Benson-Evans et al. (1975). Blum (1957) attempted to apply the transect method of the terrestrial plant ecologists to stream algae. He strung a marked rope across the stream and recorded the presence of all the visible algal species in alternate decimetres of transect. The importance of the various species was then determined by the relative number of decimetres within which they were present. The same method was later employed by Dillard (1966, 1969), whilst Squires et al. (1973) modified it to give an estimate of cover. Holmes and Whitton (1977) describe a method for large scale surveys, in which the entire length of a river is treated as a transect. The presence or absence of macroscopically recognizable species is recorded for each 0.5 km length of the river, the relative abundance on passing downstream then being indicated by the total number of 0.5 km lengths in which a species is present in successive 10 km lengths of river. In some cases, it may be desirable to remove quantities of

macroscopic algae for subsequent biomass determination; Pitcairn and Hawkes (1973) report the use of a cylindrical corer to enclose 0.1 m^2 of the river bed for the removal of the filamentous green alga Cladophora (see also Section 6.2.2).

3.1.1.4 Epiphytic algae

The epiphytic algal flora associated with larger algae, bryophytes and angiosperms in running waters may itself assume a variety of growth forms, from closely adherent thin layers to loosely attached amorphous masses. In some cases, it may be possible to subject the macrophyte material to direct microscopic examination, or even to remove the epidermal layer for the same purpose (Sladeckova, 1962).

For most quantitative purposes, however, it has been usual to remove the epiphytic algae completely from a known area, or (more readily but less satisfactorily) a known volume or biomass of macrophyte material. Physical agitation is often sufficient; Knudson (1957) placed measured lengths of macrophyte stems in a stoppered bottle containing water and shook vigorously to remove the epiphytes, whilst Hargreaves and Wood (1967) employed a magnetic stirrer to achieve the same effect. Thurman and Kuehne (1952) sampled algae epiphytic on Cladophora by preparing a cylinder of filaments 1cm in diameter, from which 1cm lengths were cut off, transferred to 4% formaldehyde solution and shaken. Other workers have advocated scraping (Young, 1945; Sladeckova, 1962) or the use of water jets and brushing (Hickman, 1971) to aid the removal process. Douglas (1958) employed a specially

designed grinding machine, driven by electric motor, to remove the epiphytes from moss samples of known volume.

Epiphytic attachment to the macrophyte surface commonly appears to be effected by mucilage-like polysaccharides (O'Colla, 1962). It was therefore postulated by Gough and Woelkerling (1976) that removal could be accomplished by a combination of physical agitation and acid hydrolysis. The method they developed involves repeated agitation in Formol Acetic Alcohol and is said to result in very efficient removal of epiphytes from different macrophytes of varying gross morphology.

The special technique used by Cattaneo (1978), a modification of the collodion membrane stripping technique of Margalef (1949), has already been mentioned.

3.1.2 Artificial Substrata

Artificial substrata have been employed widely to overcome the many difficulties associated with the quantitative sampling of natural substrata. Any convenient number of artificial surfaces, made for example of glass or plastic, may be secured in position by the most suitable means, and for the desired period of time, and then recovered and transported to the laboratory for further treatment and examination. Direct microscopic observation may be possible, or the organisms may be removed from a known area of the artificial surface. The theoretical advantages are clear: artificial substrata may be positioned in rivers where the study of natural substrata is difficult or unproductive, the problem of

the heterogeneity of natural substrata is eliminated, quantitative work is more readily carried out, and the method can be standardized, adapted for particular studies or requirements, and for procedural efficiency.

The entire subject has been reviewed comprehensively and in some detail, with the aid of illustrations, by Sladeckova (1962), whilst most of the authors cited at the beginning of Section 3.1 have also provided valuable information and comment. Owing to the sheer volume and diversity of the literature, the following account is intended to be selective and critical, rather than comprehensive.

The origins and historical development of the method are difficult to trace. Although artificial surfaces such as glass plates were undoubtedly in use towards the end of the nineteenth century for laboratory studies on the attached organisms (Lund and Talling, 1957; Sladeckova, 1962), probably the first worker to record the extensive use of artificial substrata for the collection of samples in the field was E. Hentschel (cited by Sladeckova, 1962), whose work on aquatic microorganisms in the Hamburg area was published between 1915 and 1925. A number of different devices were described by this author, including glass slides inserted into hollow bricks, or clipped to tiles (which could then be suspended in position as desired), and glass slides and celluloid plates suspended directly from cords.

The first extensive use of artificial substrata in British rivers was made during the classic series of surveys carried out

by R.W. Butcher and his co-workers between 1930 and 1950 (also cited by Sladeckova, 1962). The apparatus used in these investigations consisted of a metal photographic frame holding five glass slides, which again could be anchored in position as desired.

Since the time of these investigations, artificial substrata have been employed widely in Europe and the United States of America, although only to a modest degree in Great Britain. Glass slides have been particularly popular, presumably because they are readily available, relatively inexpensive, and convenient to handle, especially if direct microscopic examination is to be carried out. One of the best known sampling devices is the Catherwood Diatometer (Patrick et al., 1954), essentially a floating slide holder anchored to the river bed. This apparatus has itself undergone various design modifications (e.g. Hohn and Hellerman, 1963) as well as inspiring a variety of imitations (e.g. Yount, 1956; Trembley, 1960; Foerster, 1969; Tippett, 1970; Anderson and Paulson, 1972; Coste and Verrel, 1978). Glass slides have also been used extensively for productivity studies in various habitats (Sladecek and Sladeckova, 1964; Vollenweider, 1974).

Various plastics, particularly thermoplastic resins, have also been used as artificial substrata. Hohn and Hellerman (1963) sampled the diatom assemblages growing on the Styrofoam floats fitted to Catherwood Diatometers. Several workers have used Plexiglas plates, particularly in stream productivity studies (e.g. Grzenda and Brehmer, 1960; Kevern et al., 1966; King and Ball, 1966). More recently, plastic sheeting has been used for

river survey work by Besch et al. (1972) and by the European workers Backhaus (1973) and Friedrich (1973).

A number of other materials have also been used as artificial substrata in freshwater survey work. According to Sladeckova (1962) and Wetzel and Westlake (1974), these include various tiles, bricks and slates, concrete, asbestos, eternite, earthenware, a variety of metals, and bare stone and wood surfaces. Beers and Neuhold (1968) described a technique for coating concrete blocks with paraffin wax; the wax layer bearing the organisms could be removed and the blocks recoated with wax in the field. Wilson et al. (1960) used artificial substrata to study the growth of sewage fungus in a river - they used tiles contained in open wooden boxes attached to buoys.

Although the literature abounds with data generated by the use of artificial substrata, the ecological significance of the method is difficult to assess. Direct comparisons between different studies are difficult to make, owing to the different types of habitat in which artificial surfaces have been exposed, and differences in experimental design, particularly immersion times, which have varied from a few days to several months. The most valuable studies are therefore those in which a critical or comparative approach has been adopted. A number of workers have carried out studies on the colonization, taxonomic succession and biomass accumulation on artificial substrata in both lentic and lotic waters, and some of these have also included parallel observations on the corresponding natural substrata. In the following discussion, the emphasis is placed on important work

carried out since the appearance of Sladeckova's (1962) review.

3.1.2.1 Development of the attached assemblages

Jones (1978) studied the accumulation of algal biomass on polyurethane foam blocks exposed for periods of several weeks in a small lake in central Tennessee. Two studies were carried out; the first in late winter and spring, and the second in summer. In the first study, chlorophyll a levels showed a sharp initial increase but in the summer study there was a lag period of 7-12 days before chlorophyll a levels began to rise. In both studies, chlorophyll a values stabilized at similar levels, but ash-free dry weight values increased steadily, indicating that total organic matter on the blocks continued to increase even after algal biomass had reached equilibrium. A mathematical model of biomass accumulation was constructed, postulating three major processes - photosynthesis, respiration and passive accumulation, which were modulated by three environmental factors - light, temperature and plankton chlorophyll a levels. This model indicated that biomass levels early in colonization depended largely on passive accumulation from the plankton.

Several other workers have also reported a more or less steady rise in algal biomass on artificial substrata in both lentic and lotic systems, usually over a period of weeks from the data of immersion (e.g. Kevern et al., 1966; King and Ball, 1966; Herder-Brouwer, 1975). Eventually, however, biomass values tend either to stabilize, or to fall rapidly to a much lower level. Stabilization presumably represents an equilibrium state in which

loss of organic matter is balanced by new growth, whilst sharp decreases in biomass represent the sudden loss of material, or 'sloughing'. This would be expected to occur particularly in lotic systems (e.g. King and Ball, 1966), but as Kevern et al., (1966) pointed out, sloughing is likely to occur eventually even at the slowest current velocities, owing to the inevitable breakdown of the oldest layers attached directly to the artificial surface itself.

Jordan and Staley (1976) employed transmission electron microscopy to study succession on electron microscope grids immersed in Lake Washington for 1, 2, 6 and 10 days. The numbers, biomass and diversity of attached organisms increased with time. The most important pioneer colonists were heterotrophic bacteria, but after 10 days immersion the grids were found to support a greater variety of organisms, including diatoms and filamentous algae. It was noticeable that some of the organisms found in the earlier stages of the study later disappeared, to be replaced by others not present initially.

Paul et al., (1977) employed scanning electron microscopy to study succession on natural (sycamore leaf) and artificial (polyurethane foam) substrata in lentic and lotic systems in the State of Virginia. The rate of colonization and the taxonomic composition of the assemblages varied according to the type of substratum and the type of aquatic system. Leaf material was immersed in a river, and polyurethane foam in the river and in a pond. Colonization of both types of substratum was rapid in the river, but the succession of organisms differed; the leaf substrata

were colonized principally by bacteria and fungi, whilst the polyurethane foam was colonized principally by algae, particularly diatoms. The foam substrata in the pond were colonized relatively slowly, with bacteria the most important pioneers. It is difficult to make direct comparisons between the pond and the river studies owing to differences in the sampling intervals employed, and it seems possible that bacterial colonization may have preceded the appearance of algae on the foam substrata in the river. In all cases, however, it seemed that early colonization served to modify the artificial surfaces physically and biochemically, thus probably influencing subsequent colonization.

Reisen and Spencer (1970) studied diatom succession on glass slides in a South Carolina stream. As postulated earlier by McIntire (1966), as a result of studies involving laboratory streams, it appeared that diatom attachment was more pronounced at slow current velocities, but that subsequent growth and reproduction on the slides was encouraged by higher current velocities. This would explain why, in short term studies involving artificial substrata, the highest diatom densities have often been reported from relatively low current velocities, whilst in long term studies the reverse seems to be the case. A further complication arises in that different diatom genera apparently exhibit different relative attachment and growth characteristics at different current velocities, and that the relative abundance of the initial colonists may subsequently change as a result of differential population growth rates and eventual competition for space on the artificial surface.

Scanning electron microscopy was employed by Dickman and Gochnauer (1978) to study microbial succession over a 4 week period on gray slate tiles placed in a shallow, fast flowing Quebec stream. The investigation was also designed to study the impact of elevated salt levels in the stream; sodium chloride was added to a concentration of 1000 $mg\,l^{-1}$ and a station from the area thus affected was compared with an upstream control site. The general pattern of colonization and succession was similar at both stations; the first colonists were bacteria, but these were followed closely by increasing numbers of algae, particularly diatoms and blue-greens. Initially, taxonomic diversity on the tiles appeared to be a function of the rate of immigration of new species, but by the second week an equilibrium was apparently attained, at which diversity and standing crop were probably influenced more by grazing pressure, complicated by the difference in salt concentration between the two stations. The tiles chosen for this study were reported to be very similar in colour and texture to the natural substrata in the stream, but although no detailed comparisons were made, it was noticed that certain of the algae present on the larger stones in the stream, particularly filamentous greens, did not become well established on the tiles within the 4 week study period.

The studies discussed so far indicate the difficulties involved in the interpretation of temporal change, both qualitative and quantitative, occurring on artificial surfaces exposed in aquatic systems. Changes in species composition in particular might simply reflect similar changes occurring in the surrounding aquatic habitat, but might also involve distinct

ecological succession on the artificial surface itself. Herder-Brouwer (1975) performed an experiment designed to evaluate the relative importance of these two processes in ditches in the Botanical Gardens at the Free University of Amsterdam. Four sets of glass slides were immersed in a staggered time sequence over a 16 week period, and each set was sampled at intervals of 2 weeks following immersion. The entire study lasted 20 weeks from April to September; in this way, it was possible to compare slides collected at the same time but representing different exposure periods, as well as slides of the same 'age', albeit collected at different times. Greater taxonomic similarity was found between slides collected at the same time than slides of the same age, and it was concluded that the slides were reflecting seasonal changes in the ditch biota to a greater extent than successional changes peculiar to themselves.

A similar experiment, conducted by Cattaneo et al. (1975) in the Ticino River, Italy, yielded rather different results. In this case, there was some evidence of age-related succession; a diverse and variable diatom assemblage persisted on all slides for the first 2 weeks, but by the fourth week this had largely been replaced by blue-greens, to form an assemblage closely resembling the natural epilithon. This assemblage persisted on the slides until the end of the 7 week study. There was a progressive decline in species diversity as succession proceeded. Chlorophyll _a_, dry weight and organic C and N peaked at 3 to 4 weeks, following which chlorophyll _a_ and dry weight declined whilst organic C and N stabilized.

Patrick et al. (1954) and Yount (1956) also found decreases in diatom diversity on glass slides subjected to prolonged exposure. This could be the result of competitive exclusion of the less well adapted species, but as MacFadyen (1963) pointed out, the interpretation of results from studies involving artificial substrata is often complicated by the preponderating influence of chance arrivals, which would be rapidly eliminated if competition were more intense. Such forms may occur very sporadically and for short periods only, and it is often very difficult 'to make sense' of species lists from such investigations.

3.1.2.2 Influence of substratum type and position

The colour and texture of the artificial surface, and its orientation in relation to the water surface and direction of flow may be significant. Godward (1934) provided glass slides with backings of green and black. After 12 days immersion in a pond, the green slides were found to support a much greater algal standing crop (in terms of numbers of individuals per unit area) than the black slides. This difference was less apparent at about 2 months, however, probably because the colour difference had by this time disappeared owing to the accumulation of material on the slides. This same author also found that slides scored with a cross-hatching of fine grooves were colonized more readily by algae, at least over the first 1-2 weeks of exposure. During this period, colonization occurred preferentially in the grooves, but since no species were actually restricted to the grooves, the treatment probably had little ultimate effect on taxonomic composition.

This seems consistent with the general statement made later by Sladeckova (1962), that the surface texture of artificial substrata seems to affect the standing crop rather than the taxonomic composition of the attached assemblages. Presumably, the increased surface area of rough substrata would be expected to encourage the development of a higher algal standing crop, by presenting a greater number of more suitable attachment sites. Herder-Brouwer (1975) found that wood and sand-blasted glass surfaces accumulated a higher algal biomass than smooth glass. In an earlier investigation, however, Castenholz (1960) found no apparent differences between sand-blasted and smooth glass, and suggested that the early formation of a bacterial film on the glass surfaces might effectively render them very similar in relation to subsequent algal colonization.

In the laboratory studies conducted by Harper and Harper (1967), diatoms were found to adhere more strongly to glass than to clear polystyrene, and to vertical more strongly than to horizontal surfaces. When a surface bearing diatom cells was tilted from horizontal to vertical, only 1% of the original number remained after an hour. These findings were interpreted by Tippett (1970) as suggesting that only those diatoms capable of strong adhesion can remain attached to vertical glass, that glass would support smaller populations than plastic, and that horizontal surfaces would support a richer flora than vertical surfaces. Indeed, it has frequently been noted that horizontal substrata tend to accumulate more organic matter than vertical substrata, although the precise ratio seems to vary according to the season and is apparently higher in lentic (Newcombe, 1949;

Castenholz, 1960) than in lotic (King and Ball, 1966) waters. It should also be remembered that horizontal substrata are more likely to accumulate greater quantities of non-living material, both organic and inorganic. It is for this reason that a number of workers have preferred to use vertically positioned substrata, as in the original Catherwood Diatometer (Patrick et al., 1954). Newcombe (1949) noticed that the upper surfaces of horizontal slides accumulated rather more material than the undersides, but Castenholz (1960) found this to be the case only under conditions of high productivity, and also stated that the taxonomic composition of the assemblages on both sides was substantially the same. It was however claimed by Sladeckova (1962) that if the difference in light intensity was sufficient, this might lead to the development of a predominently autotrophic assemblage on the upper surface, and a heterotrophic assemblage on the lower surface, of a horizontally positioned substratum.

Biswas and Mokry (1978) studied the algal growth over a 10 month period on a 'benthobservatory' - essentially a partially submerged concrete box with windows set below the water surface. This structure was positioned in a stream in such a way that one window faced upstream, one faced downstream, and of the two remaining side windows, one faced a ponded region of the stream and the other was exposed to the current, parallel to the direction of flow. Each window was found to support a different algal flora - the window facing the ponded region supported the greatest diversity in algal species, whilst the window facing upstream supported the least diversity. The upstream window was also found to support the lowest algal biomass. These results

were explained largely in terms of differences in physical stress and grazing pressure, both of which were greatest on the upstream window.

Relatively little is known of the influence of the depth of artificial substrata below the water surface in rivers, presumably because in most studies, substrata are either attached to floats and therefore maintain constant depth, or are fixed in position and are therefore subject to random fluctuations in depth as the water level rises and falls. Limited data are however available from lentic situations. Sladeckova (1966) exposed glass slides at depth intervals of 1m, from the surface to the bottom of reservoirs in Czechoslovakia (one reservoir was 9m in depth). In most cases, five zones could be recognised with increasing depth: a surface zone without true periphyton, a zone of algal producers, a transition zone of mixed producers and consumers, e.g. protozoa and rotifers, a zone dominated by the consumers, and a bottom zone with bacteria and larger benthic organisms. The zonation pattern varied with environmental conditions, including seasonal and water quality changes. As might be expected, algal development took place predominantly within the euphotic zone.

Neal et al (1967) suspended polyethylene tapes 1.5m in length and 3.8cm wide vertically in the radioactively contaminated White Oak Lake, Tennessee (maximum depth 2.4m). After two weeks immersion, biomass accumulation reached equilibrium on the upper tape sections, but full development on the deeper sections took longer. Maximum biomass occurred at depths of about 25-50cm. A succession pattern was evident - blue-greens were followed by

diatoms and filamentous green algae, but the blue-greens tended to maintain dominance in the deeper zones, whilst in the upper zones of higher light intensity, the green algae tended to predominate. Diatoms, although important, were never dominant on the tapes.

3.1.2.3 Similarity to natural substrata

The extent to which the assemblages growing on artificial substrata resemble the natural assemblages at the same locality is clearly a matter of some interest. Although several comparative studies have now been carried out in both lentic and lotic waters, the results have differed considerably, and it remains difficult to present a reasonably objective assessment. Some workers (e.g. Patrick et al., 1954; Castenholz, 1960; Dor, 1970; Cattaneo et al., 1975) claim to have found great similarities between the assemblages on natural and artificial substrata, whilst others (e.g. Foerster and Schlichting, 1965; Tippett, 1970; Brown, 1976; Siver, 1977) have found significant differences. Hohn and Hellerman (1963) found that the assemblages growing on glass and Styrofoam following an exposure period of 2 weeks were comparable to those growing on the corresponding natural substrata only at temperatures of 16 ^{o}C and above. At 3 ^{o}C, the Styrofoam continued to mimic the natural substrata, but the assemblages growing on glass underwent a marked reduction in diversity. Further studies suggested that Styrofoam was also more representative of natural substrata than glass over a wider range of current velocity.

Lund and Talling (1957) were careful to point out that some algae rarely if ever appear on glass (at least within the relatively short time periods usually employed), whilst other algae commonly reported from artificial substrata are apparently little known from natural substrata. Many workers have reported that filamentous algae in particular seem reluctant to colonize artificial substrata, e.g. Castenholz, (1960), Brown (1976) and Dickman and Gochnauer (1978).

These considerations have caused many authors to express reservations concerning the use of artificial substrata as ecological tools. Wetzel (1975) stated that although the number of studies, many of which were conducted most critically, has been large, the discrepancies found between populations and numbers on natural and artificial substrata are sufficient to necessitate thorough evaluation in each study in which artificial substrata are used. Whitton (1975) suggested that a detailed comparative study of the methods is required. Tippett (1970) was severely critical, stating that at its best, the method can only be comparative, showing relative changes in the flora.

It could be argued, however, that for biological surveillance purposes (Section 1), a comparative approach is all that is required, provided of course that the changes involved can be readily interpreted in terms of water quality.

3.1.3 Sample Analysis

For biological surveillance purposes, sample analysis is almost invariably a laboratory procedure involving the identification of the organisms present, together with some evaluation of their quantitative importance. Only in this way can field changes of potential indicator value (Section 1.2.3) be detected. Quantitative work is subject to the chance errors involved in any sampling process; this problem is discussed in greater detail later in this section (3.1.3.3).

3.1.3.1 Identification

Generally, a high degree of specialist experience and expertise is required for the reliable identification of the entire range of important freshwater algae to the species level. The taxonomic literature, although extensive, is frequently complex, obscure or out of date, and a variety of languages is represented. A guide to algal keys (excluding seaweeds) has been presented by George (1976), whilst the coded check-list of the commoner British freshwater algae prepared by Whitton et al. (1978) lists most of the important texts and references. The classic text of West and Fritsch (1927) remains the only reasonably comprehensive account of the British freshwater algae, but since many taxa appear to be very widely distributed, many of the more recent keys and monographs, constructed originally for other geographical regions, may be used in Britain. Particularly valuable are the North American texts of Smith (1950) and Prescott (1962), and the European volumes of Bourrelly (1966, 1968,

1970) and Hustedt (1930), the latter being the most useful general diatom flora available. At the Windermere Laboratory of the Freshwater Biological Association is housed the Fritsch Collection of illustrations of freshwater algae. This is essentially a collection of photocopies of published pictures of freshwater algae, together with a few marine or brackish water species, bacteria and protozoa (Lund, 1971). In 1964, when the collection contained some 160,000 illustrations, it was copied and later issued as a microfische edition, which is supplemented as the original collection expands.

Special techniques and facilities are sometimes required for identification purposes. The identification of many diatoms to species depends on a clear view of the detailed ornamentation of the siliceous cell wall or frustule. This is achieved by removing the organic matter from in and around the frustules, and mounting them in a special permanent mountant of high refractive index. A number of different methods have been used for the removal of organic matter from samples, including ashing at high temperature (Patrick et al., 1954; Castenholz, 1960; Dillard, 1969) and treatment with acid digestion mixtures (e.g. Hohn and Hellerman, 1963; Hasle and Fryxell, 1970; Siver, 1977).

For some algae, material must be in the reproductive state for reliable identification. Further complications arise from the taxonomic uncertainty or fluidity associated with some groups. The relative inaccessibility of the freshwater algae to the non-specialist means that our knowledge of the British

flora is relatively poor; as Whitton (1974) remarked, "anyone used to studying flowering plants, bryophytes or lichens, and who decided to expand his interests to include freshwater algae, might well be shocked at the state of the subject. He would find that not only is there no mapping scheme, but also that for most of the groups there is not even any sort of British flora or published check-list." Although the situation is slowly improving, these problems must surely represent a considerable disadvantage to the essentially practical worker interested in using the algae for biological surveillance.

3.1.3.2 Evaluation of quantitative importance

The evaluation of quantitative importance, like the collection of samples, is made difficult by the size range and morphological diversity of the organisms involved. The problem is to accommodate single cells, aggregations of cells, colonies, filaments and multicellular thalli within the same standard scale of quantitative importance.

Biomass and photosynthetic pigment content are frequently used as measures of total standing crop; these determinations are discussed in some detail by Vollenweider (1974), in relation to primary productivity studies. In general, the direct gravimetric determination of biomass is inaccurate because most samples contain a significant but variable proportion of extraneous inorganic and organic material. For this reason, ash-free dry weight is usually preferable to wet weight or simple dry weight. The quantitative determination of photosynthetic

pigments has been used for many years as a measure of algal standing crop. Whatever pigments or groups of pigments are used, the method is basically the same: pigment extraction by an organic solvent is followed by specific photometric determination of the optical density or fluorescence of the resulting solution (Lund and Talling, 1957). Most attention has been given to the determination of chlorophyll a, which is normally the most important and abundant pigment in living freshwater algae (Round, 1973). A detailed discussion of techniques is beyond the scope of the present review; it should be mentioned, however, that many techniques were developed originally for planktonic algae, and may not be directly suitable for benthic assemblages. This problem has been considered in some detail by Marker (1972), whose subsequent work on stream benthic algae (Marker, 1976a, 1976b; Marker and Gunn, 1977) provides further valuable information on this type of work.

Clearly, biomass and pigment determinations are unable to provide information on the quantitative importance of individual taxa, unless relatively pure unialgal samples can be obtained. This is practical only in the case of certain macroscopic forms, e.g. Cladophora (Section 6). It has already been mentioned (Section 3.1.1) that it may be possible to evaluate macroscopic growths directly, without removal, in the field, either subjectively or by means of transect techniques adapted from terrestrial ecology. Samples containing large numbers of microscopic forms must however be returned to the laboratory for further analysis, and many workers have attempted to perform all counts on such samples. General reviews of counting techniques have been

presented by Lund and Talling (1957) and Sladeckova (1962). Counts may sometimes be performed by direct observation of the natural or artificial surface (e.g. Reisen and Spencer, 1970; Tippett, 1970; Jones, 1974; Brown, 1976); all that is required to count a sufficiently large number of organisms from a known area. In most sampling procedures, however, the algae are removed from a known area of surface, either in the field or later in the laboratory. Such samples can be mounted for microscopic examination (either wet or as permanent diatom preparations), and if this procedure is quantitatively controlled, these preparations can then be used for counting purposes. No elaborate apparatus is required for this type of count; Edmondson (1974) advocates the use of a calibrated pipette to dispense a drop of algal suspension of known volume on to the surface of a clean microscope slide. A standard 22mm x 22mm coverslip may then be positioned over the drop in such a way that the liquid disperses uniformly and precisely beneath it, and counts performed by scanning microtransects of the preparation. Although this method was intended originally for plankton samples, it has been used by Benson-Evans et al. (1975) for the analysis of benthic samples.

Many workers however have preferred to perform counts in one of the specially designed chambers or cells; detailed accounts of the two most popular techniques - the inverted microscope technique and the Sedgwick-Rafter (S-R) microlitre counting cell - have been presented by Lund et al. (1958) and Woelkerling et al (1976) respectively. The basic principles are similar for both methods; a sample of algae collected from a known area or quantity of substratum is suspended uniformly in a known volume of water,

and this entire sample, or more usually a subsample of known volume, is then transferred to a counting cell and the algae allowed to settle for microscopical examination on to the floor of the cell. Iodine solution is often added at this stage to kill, stain and weight the algae. Observation is carried out using either an inverted microscope, or, in the case of the S-R cell, a conventional microscope; in either case, counts are carried out by scanning the entire floor of the cell or smaller known areas of it. The appropriate back calculations will yield an estimate of the number of organisms in the sample, the accuracy of this depending upon the magnitude of the errors inherent in the procedure. The advantages, disadvantages and statistical properties of these methods have been discussed in detail by the authors cited above but it should be remembered that most procedures were developed originally for planktonic algae. Benthic samples usually contain large quantities of extraneous material, which may seriously interfere with counting, and as mentioned earlier, the size range and morphological diversity of the organisms themselves make it difficult to standardize the counting unit. A number of workers have attempted to overcome this problem as far as possible by adopting certain counting conventions (Hellawell, 1978). Colonies and filaments, for example, can be counted as single entities only if the number of cells is reasonably constant in each colony or filament; otherwise it becomes necessary to estimate actual cell numbers. If this is not possible, then colony sizes or filament lengths may have to be measured. Other workers have preferred to express results in terms of cell volume - this seems justifiable for biomass estimations (even though it is practically difficult and

a potential source of error), but for water quality surveillance purposes there seems little reason to assume that larger cells are intrinsically more important than smaller cells.

Jones (1974) compared the results of diatom counts performed directly on stone surfaces, with those obtained by a more conventional removal method; the algae were scraped from known areas of stone surface, cleaned in acid, neutralised and then membrane filtered. The filters were dried and cleared with cedar wood oil and the diatoms in a standard number of microscope fields counted. Significantly higher counts were obtained by the direct count procedure in all the samples examined. Since the removal procedure was found to be 100% efficient, and considerable care was taken to transfer all the scraped material to the membranes, the lower counts on the membranes were ascribed to the presence of detritus masking some of the diatoms, and the breakage of diatoms during the treatment into fragments too small to identify or count.

Eaton and Moss (1966) found that temporary wet mounts of living diatoms were more satisfactory for counting purposes than permanent preparations. Higher counts were obtained using the permanent mounts, owing to the presence of the frustules of diatoms already dead and empty and the time of collection, and also the fact that many frustules were split into their component valves by the cleaning process.

A number of more elaborate counting techniques have been developed, but for various reasons are not widely used in the

analyses of benthic samples. In general, electronic counting techniques (Vollenweider, 1974; Hellawell, 1978) have too many limitations, whilst the advanced optical systems described by Cairns et al (1977) for the automated identification and counting of diatoms are as yet not sufficiently well validated, either technically or economically, for wider adoption.

3.1.3.3 Quantitative procedures and the semi-quantitative compromise

All methods of estimating the abundance of algae which involve taking relatively small samples from a large population, followed by further subsamples for purposes of counting, will be subject to the chance errors involved in any sampling process. This could be an important problem in large scale surveillance programmes; Hobro and Willen (1977), for example, compared the routine methods employed for phytoplankton counts by a number of laboratories around Europe. Although most of the laboratories employed an inverted microscope technique, a number of important variations were found, notably in the methods of preservation and the counting regimes adopted. This resulted in practice in an unacceptable degree of variation in the counts performed by different laboratories on the same sample.

It is clearly important to be able to establish the main sources of error and their magnitude. By determining the components of variance introduced at each stage of the sampling process, it should be possible to decide which stages could best be replicated to make routine estimates as reliable as possible with a minimum of work. Descy (1976a), working on

benthic diatoms in the Belgian Meuse, found that the variance introduced at the sampling stage could be decreased by increasing the number of replicate samples taken, but there came a point beyond which further replication did not result in a further decrease in variance. This occurred after only three samples of $415mm^2$ had been taken, but as the author pointed out, more replicate samples would have to be taken from waters supporting a less regularly dispersed flora. The statistics of the counting process have been discussed for the inverted microscope by Lund et al (1958) and for the S-R cell by Woelkerling et al. (1976); in general it seems preferable to perform a relatively small number of counts on each of a larger number of separate subsamples.

The analysis of variance described by Davies (1956) has been used by a number of workers (Eaton and Moss, 1966; Hickman, 1969; Brown and Austin, 1971) to evaluate sampling procedures for attached algae. It is possible to determine the components of variance introduced at each stage in a procedure, from the collection of samples, through subsampling and so to the final counts, and also to test different sampling, subsampling and counting regimes so that the most economical procedure for a required degree of accuracy may be adopted. From the limited number of published accounts available, it would seem that much of the overall variance of most procedures is introduced at the sampling stage or at the final counting stage, especially if too few organisms are counted. Clearly, increasing the number of replicates at any stage would increase the overall reliablity of any procedure, but as Brown and Austin (1971) pointed out, the

work involved in carrying out the most reliable sampling designs may well be prohibitive for most routine purposes.

Because of the difficulties involved in performing reliable quantitative work, a number of authors have preferred to express their results in some 'semi-quantitative' manner. The most usual approach is to collect samples according to a number of stated conventions, and then either to make cell counts to determine the percentage contribution of each taxon to the sample, or simply to make an essentially subjective evaluation of relative abundance, usually by assigning each taxon to one of a series of abundance categories. In some cases, these abundance categories may themselves have a loosely defined quantitative basis (e.g. Benson-Evans et al., 1967). Sladeckova (1962) and Whitton (1979) have cited a number of studies in which semi-quantitative analyses have been used, and although the approach is subject to criticism, it must be admitted that it represents a most useful compromise between strict quantitative work, which is often difficult and time-consuming, and simple qualitative work, which conveys no quantitative information at all. For this reason, the semi-quantitative approach would appear to be worthy of consideration for biological surveillance purposes.

3.2 The ecology of the benthic algae in relation to river water quality surveillance

The composition of any river benthic assemblage at any point in space and time is determined by a number of more or less interacting physical, chemical and biological factors, or determinants. Spatial and temporal changes in these determinants result in spatial and temporal changes in the composition and structure of the assemblages. Anthropogenic pollution, as defined in Section 1.1, usually acts by changing one or more natural determinants, or by introducing one or more new determinants; in either case the determinants involved become water quality criteria in relation to the legitimate use or uses impaired by their influence.

The main objective of biological surveillance is to detect changes in the composition and structure of biological assemblages that are significant in relation to water quality. At any water quality, however, biological changes may result, directly or indirectly, from the influence of determinants not themselves directly related to water quality. The main problem therefore lies in the correct interpretation of surveillance data.

In Section 3.2.1, the effects of the more important environmental determinants on river benthic algal assemblages are discussed; this includes those determinants that are not usually considered as water quality criteria, as well as those that are. This is followed in Section 3.2.2 by a review of the ways in which algal surveillance data have actually been applied in the assessment of water quality.

3.2.1 Ecological Basis

A general review of the ecology of benthic algae in all types of freshwater habitat, but with emphasis on the epipelic assemblages of lentic waters, has been presented by Round (1964). The river algae have been considered specifically by Blum (1956), Hynes (1970) and Whitton (1975). A general review of the ecology of freshwater diatoms and diatom assemblages has been presented by Patrick (1977). The effects of pollution on freshwater algae have been discussed by Hynes (1960), Cairns et al. (1972) and Whitton (1979). The last author has also written two specialized reviews: the first concerning attached photosynthetic plants in certain extreme flowing water environments (Whitton, 1972), and the second dealing with well-documented changes in the British freshwater algal flora (Whitton, 1974). The following general account owes much to the work of these authors, although it must be realised that even now there is a massive body of literature awaiting further review. Whitton (1975) for example presents a list of over 100 detailed algal surveys carried out in flowing waters in different parts of the world, most of them since Blum's (1956) review, and states that many of these have seldom been quoted by other authors.

Our knowledge of the ecology of river benthic algae is derived largely from field observation, and very few supporting laboratory experiments have been carried out. As Whitton (1975) observes, studies on lotic algae are in many ways less advanced than studies on the phytoplankton of standing waters. The reasons for this are largely practical and economic - the river benthic algae are in many ways more difficult to study than the plankton,

and are in any case considered to be of less economic importance. Furthermore, there seems to be no entirely satisfactory theoretical framework which can be used to bring together data from diverse studies and thus give some perspective to the subject as a whole. Although rivers can be classified in a variety of ways (Hawkes, 1975), they do not seem to fall into such distinct hydrological or ecological types as do lakes. Thus, although many streams exhibit longitudinal and seasonal changes in the composition and structure of the benthic algal assemblages, differences between different streams, and even in the same stream from one year to the next, make it very difficult to generalize. In many streams, marked changes seem to occur over very small distances and within very short time periods. The often high degree of spatial heterogeneity at the local level has already been mentioned in connection with sample collection (Section 3.1), and as Blum (1956) states: "One of the most striking phenomena in nature ..... is that of the frequently abrupt changes which occur from month to month in the algal vegetation of streams. Visits to a small stream spaced at weekly intervals will often reveal the complete disappearance within a period of only six to ten days of an erstwhile conspicuous alga."

Most of the authors cited at the beginning of this section agree that physical factors, particularly substratum stability, current velocity, temperature and light are very important. The recent series of studies conducted by Moore (1976; 1977a, b, c, d; 1978) on seasonal changes in a variety of flowing water habitats in England also indicates the importance of these physical factors.

Water chemistry is generally acknowledged as being of

significance, although the influence of specific factors or combinations of factors is less well established, except in the case of polluting discharges causing marked chemical (e.g. toxic) or nutritional (e.g. organic or inorganic) imbalance. Most authors also acknowledge that biotic interactions, particularly competition and grazing, are probably important in determining the observed patterns of field distribution, although again so little is actually known that most discussions tend to be largely speculative.

Sutcliffe (1976) has made an interesting general statement that is perhaps relevant in this context. He observes that not only are river systems individual entities with characteristics peculiar to each catchment, but that the habitat itself has increased markedly in severity in the Recent period, following the wholesale destruction of forests in northern Europe and America. Apart from the enormous reduction in the annual input of leaves, now regarded as the basis of the economy of many stream systems, the removal of forests alters the hydrology of the catchment. Formerly, it is believed, there was a steady regulated flow of water through the catchment, relatively independent of short-term fluctuations in rainfall. This has now changed to an uneven pattern of flow, with wide extremes of high and low discharge that are more immediately dependent on the frequency and volume of rainfall. In other words, the river habitat is less stable now than it was in the preceding era of widespread forest.

In view of these considerations, it is perhaps not surprising to find that most attempts to recognize developmental phenomena

such as ecological succession, taxonomic association and climax conditions in the river benthic algae have been largely unproductive (Hynes, 1970). Most species are probably simple opportunists, being available at most times but flourishing only when conditions happen to become favourable; presumably, the ability to do so is also related to a relatively high growth potential under these conditions.

The most important environmental factors are now considered, with emphasis on physical factors and water chemistry, particularly in relation to pollution.

3.2.1.1 Substratum and water movement

It is convenient to consider these two factors together, since they interact very closely. As mentioned in Section 2.2, substratum type is of sufficient importance in the ecology of attached algae to make it possible to refer to the epipelic, epipsammic, epilithic and epiphytic assemblages. It is in fact possible to list the species which have been commonly reported from these different assemblages (Round 1964, 1973), but as Hynes (1970) points out, in running waters the distinctions are not always very clear. The differences between epilithic and epiphytic floras, for example, tend to be largely statistical, with many species being merely more abundant in one than in the other.

It seems possible that the physical and chemical properties of the different substratum types may influence colonization, but there are very few firm data to confirm this. Round (1964) suggests

that the physical structure, organic content and pH of the finer sediments may be important to the epipelic assemblages. Hynes (1970) observes that different types of stone in a stream bed often acquire different amounts of epilithic flora. Whitton (1975) reports that in general a coarse sandstone surface is particularly favourable for colonization, whilst a smooth surface is colonized more slowly, presumably because particles are trapped less readily on the latter. This author also cites several instances in which the physical and chemical characteristics of certain rocks seem to influence colonization by certain algae. It is also undoubtedly true (Hynes, 1970) that different species of macrophyte are very differently colonized by epiphytes, and that even different parts of the same plant offer different qualities of surface for colonization. The latter effect may in part be a reflection of age (young shoots having had less time to acquire a flora), but dead leaves are often more heavily colonized than living leaves, and some plants seem to acquire very little periphyton whilst still alive.

It is generally agreed that the physical stability of any substratum is a very important factor, but this property can not be considered independently of water movement. In general, it would be expected that increasing current velocity would impose an increased physical stress on the substratum and on the attached algae, but the situation is complicated by the fact that current velocity is countered at the stream bed by friction and turbulence, the latter factor being related to bed roughness. In this way, different parts of the stream bed may be subjected to vastly different current pressures, resulting in a variety of microhabitats

for colonization. Above a certain critical velocity, however, the substratum at any given point may itself be set in motion, according to its inherent physical stability.

Bearing these observations in mind, it can now be said that many attached algae occur primarily or exclusively in streams, or in places such as stony lake shores where there is continuous water movement. Thus, many species seem to have a definite current demand, and different species and assemblages have been observed to become dominant at different current velocities. Blum (1960) presents some particularly striking examples of spatial distribution patterns which are probably related primarily to variations in current velocity.

Ruttner (1926) suggested that current enhances the 'physiological richness' of lotic waters by constantly renewing the supply of dissolved materials to the organism, and by preventing the accumulation of a 'shell' of depleted water. This is probably the most important explanation for the current demand of many species, and for the fact that some species seem to require faster current velocities in warm weather, when dissolved gas contents are lower. A number of experimental studies have supported this hypothesis, indicating that many algae grow better, and some will only grow in running water, and that the uptake of materials, metabolic activity and productivity of attached algae all tend to be greatest in running water (Whitford, 1960; Whitford and Schumacher, 1961, 1964; McIntire, 1966; Rodgers and Harvey, 1976).

On physically stable substrata, increasing current velocity

will tend to wash the more loosely attached forms away. Very fast currents (>5 m s^{-1}) reduce the flora to only those species that are both very firmly attached and also resistant to mechanical damage. The algal flora on rocks at such sites is usually dominated by encrusting forms and filaments with no or only moderate branching (Whitton, 1975).

Douglas (1958) found that when floods reduced the epilithic algal populations in a small stony stream in the English Lake District, the effect was more severe on stones which were rolled by the water than on fixed rock. During high water periods, stones populations remained low owing mainly to the instability of the substratum, and rock populations increased. On a return to low water levels, stones populations increased whilst rock populations declined, although sometimes after an initial increase. Similar scouring effects have also been reported by other workers, e.g. Kobayasi (1961), Minckley and Tindall (1963) and Jones (1978). In the study conducted by Douglas (1958) mentioned above, it was also noted that algal populations epiphytic on moss were relatively uninfluenced by current velocity, being affected only by very severe flooding. In a study of epiphytic algae in various aquatic habitats, including a river, Hargreaves and Wood (1967) found that all the periphyton was washed from Juncus leaves by swift currents following a period of torrential rain. Moore (1976) found that the epiphytic algal populations attached to Cladophora were maintained at times of flood, but a sharp decline in numbers occurred in the continual absence of flooding. Round (1973) presents data showing the influence of flooding on the epipelic flora; in rapidly flowing waters, diatom cell numbers show greater temporal fluctuations than they do

in slow flowing canals. The growth of algae on artificial substrata in relation to current has already been discussed in Section 3.1.2.

To summarize, then, as Wetzel (1975) stated, under favourable conditions benthic algal populations often develop profusely when stream velocities are low. These populations commonly become physically unstable when increases in current velocity occur, and large numbers are released to the water. During a spate, particularly when the abrasive action of the substratum is marked, major losses of the attached flora can occur, especially during the initial phases of increased flow.

3.2.1.2 Temperature and light

It is again convenient to consider these two factors together, since it is often difficult to distinguish between their possible field effects.

In river systems, mean temperatures tend in general to increase from source to mouth, although the amplitude of diurnal or even more rapid fluctuations in temperature tends to become less. Although certain taxa are apparently restricted to relatively cold or warm waters, it is very difficult, from field observations alone, to establish the precise relationship, if any, between temperature and growth. Certain species, e.g. Hydrurus foetidus (Chrysophyta), grow throughout most of the year at high altitudes, but at lower altitudes occur only during the colder months, or not at all. This has been taken to suggest

a definite requirement for low temperatures. Whitton (1975) however cites the example of Chrysonebula sp., an alga somewhat resembling Hydrurus, which normally flourishes in unpolluted streams in the north of England only in winter, but which will grow well throughout the summer in zinc contaminated streams, apparently owing to the absence of competition from other algae.

For most algae, the warmer seasons are the periods of maximum growth, but as Blum (1956) pointed out, the often rapid temporal changes in the abundance of particular taxa throughout these periods are not usually well correlated with temperature changes, and are probably better explained in terms of other physical, chemical and biological factors. Similarly, differences in vegetation within a small area are not usually caused by temperature differences. Thus, although temperature may be of broad significance in a relation to longitudinal changes from source to mouth, and for seasonal changes, its role often seems to be essentially secondary, indirect or incidental.

For these reasons, it is also difficult to establish the effects of heated discharges on the river benthic algal flora. Such discharges are rarely simple, the temperature increases involved are widely variable and in any case probably exert their influence indirectly through other factors. This is so particularly when the receiving watercourse is already polluted; increased temperatures may for example exacerbate the effects of organic enrichment or toxic pollution (Hynes, 1960). Much of the available information on heated discharges is reviewed by Hawkes (1969), Patrick (1969), Cairns et al., (1972) and Whitton (1972).

In general, it seems that increased temperatures tend to result in an increase in the abundance of certain taxa, coupled with a reduction in abundance, and possibly even the complete loss, of others. The green and blue-green algae in particular seem to be favoured by higher temperatures. The increase in abundance of certain taxa may also be accompanied by an increase in productivity, but presumably only if the temperature rise coincides with the temperature optima for the species involved, and if no other adverse factor has increased in importance.

Turning now to light, although the old concept of the algae as a simple phototrophic group now has to be modified (Round, 1973), this factor must still be regarded as of fundamental importance for the majority of the freshwater groups. The field situation is, however, again very complex. The daily photoperiod and the intensity of insolation depend broadly on the seasonal light climate, but are modified considerably at the microhabitat level by a variety of local factors. The most important of these are the gross structure and geographical orientation of the stream channel, weather conditions (especially cloud cover), the presence of bankside objects and the development of bankside and aquatic vegetation, bed roughness, and the depth and optical properties of the water itself. It is very difficult to investigate the effects of any of these factors on benthic algal assemblages in the field. Gallegos et al. (1977) developed a method for calculating short term variations in oxygen exchange in a river benthic algal assemblage dominated by diatoms. They found that the community responded very rapidly to changing light conditions on cloudy days, indicating a high degree of adaptation to these

conditions.

As with temperature, certain algal taxa are apparently adapted to grow at low light intensities, whilst others are favoured by, or actually seem to require, relatively high light intensities. Field observations are probably more informative than in the case of temperature, however: many rivers have well defined shaded stretches, whilst in others the effects of light are accentuated by a relatively uniform temperature regime. Hynes (1970) states that in general, many diatoms appear to be relatively indifferent to light intensity, whilst the Rhodophyta as a group tend to be adapted to low light intensities, and many Chlorophyta seem to require fairly high light intensities. Many species, particularly of green algae, are abundant in early summer and autumn, but are apparently reduced by heavy midsummer tree shade. In some species, however, e.g. Stigeoclonium tenue and Ulothrix zonata, midsummer scarcity occurs even in the absence of trees. This could be a direct temperature effect, but as Hynes (1970) observes, it could also be a reflection of the conditions under which these algae evolved before the clearing of the woodlands. There is in fact evidence to suggest that many algae may actually have been constrained by evolutionary pressure to avoid warmer waters, essentially on account of the shading effect, rather than because higher temperatures are themselves unfavourable.

Little experimental work has been done on the effect of light on stream algae, but a notable exception is the study of Phinney and McIntire (1965) on growths in laboratory channels.

They showed that a community kept at just over 18 ^{o}C increased its oxygen production rate with increasing light intensity, but that above 11,400 lux, which is considerably less than full sunlight, photosynthesis actually declined. At 8-10 ^{o}C the rate of photosynthesis continued to rise to the highest level of illumination tested; it was, however, much lower than at the warmer temperature. The community was most efficient at fairly low temperature and illumination, whilst at high temperature and low light intensity respiration actually exceeded photosynthesis. These results again probably reflect evolutionary history as outlined above.

Variation in total radiation with depth is probably of relatively minor importance in a small stream, but in a large river bearing a heavy silt load, turbidity can reduce light penetration to a point which curtails or completely prevents plant growth (Blum, 1956). Further, as Hynes (1960) points out, the deposition of silt on the river bed is also likely to have a profound effect on the algal benthos. Current velocity and substratum characteristics are again obviously important in this context, and although the true epipelic flora (Round, 1964) is apparently adapted to some degree of bed disturbance (being composed almost exclusively of motile species in streams and rivers) it can perhaps be said that in deeper reaches characterized by continuous or prolonged intermittent turbidity, the development of a benthic algal flora is likely to be severely restricted.

Many polluting discharges contain suspended solids, although as with heated discharges, these are usually associated with other

forms of pollution (most usually with organic enrichment) and the direct effects of inert solids (i.e. reduction in light penetration and silting) on the benthic flora will depend largely on the physical characteristics of the solids and of the receiving watercourse.

3.2.1.3 Water chemistry

The chemical composition of natural river waters is extremely complex and variable. As Hawkes (1975) observes, as water arrives at the surface of the earth, it already contains dissolved atmospheric gases - oxygen, carbon dioxide, oxides of nitrogen and, in atmospherically polluted areas, oxides of sulphur and phosphorus. As the water either percolates down through the soil to contribute to ground water, or flows over the surface to supplement the surface waters, it accumulates further materials, organic as well as inorganic, these differing according to the geological and ecological nature of the area. Finally, as the water flows down the river system to the sea, the concentrations of dissolved and suspended materials usually change, both as a result of natural processes, and of course the entry of effluent discharges.

Different species and assemblages of river benthic algae have been reported from waters of different chemical composition, but again our knowledge of the influence of specific factors or combinations of factors is essentially indirect, being derived from field observation alone. The chemical variables most often mentioned in relation to the occurrence of the benthic algae are

the dissolved gases, hardness, pH, acidity, alkalinity, salinity, metals, organic matter, and the plant nutrients, particularly nitrogen and phosphorus. These are discussed by the authors mentioned at the beginning of this section, and are mentioned further here only in relation to the most important types of river pollution.

(i) Chemical and toxic pollution

Very little is known of the direct effects of simple deoxygenation, osmotic stress and extreme pH (see Table 1.1) on the composition and structure of river benthic algal assemblages. These conditions rarely occur in isolation, again usually being associated with other forms of pollution, particularly toxic and organic pollution.

Our knowledge of the effects of toxic substances on the river benthic algae is confined largely to metals. The occurrence of trace metals in river waters has been reviewed by Wilson (1976), whilst Whitton (1970c) has presented a review of the effects of heavy metals on freshwater algae, and Whitton and Say (1975) have presented a comprehensive discussion of the ecological significance of heavy metals generally in lotic waters.

Metal contamination from mining activity in Cardiganshire, Wales, was studied in some detail by several workers during the 1920's and occasional observations have been made since then (see Hynes, 1960, and Whitton, 1970c). Most of the mines had actually ceased to operate before the investigations began, the

pollution arising from the oxidation of the exposed ores, galena and zincblende, to lead and zinc sulphates which then drained off into the rivers. In west Wales, the waters are soft and slightly acid, thereby offering no protection from the metals, which are normally precipitated in hard water. Furthermore, toxic conditions have in some instances persisted for considerable periods of time, with zinc, for example, continuing to leach out of some dumps for at least 35 years following the cessation of mining operations. Although there is quite a large literature on these rivers, it is difficult to draw any firm conclusions concerning the extent to which the various observations recorded were due to high levels of zinc or lead, or in some cases, silting. In general, however, it seems that high levels of these metals are likely to result in a considerable reduction in the number of species present, but that a few taxa, particularly the red alga Lemanea, are especially resistant to both zinc and lead. The algal flora is also apparently capable of recovery, given decreasing severity of metal pollution, both in space and in time.

An instance of copper pollution in the river Churnet, a tributary of the river Dove (Midlands) was described by Pentelow and Butcher (1938) and later by Butcher (1946, 1955). At the time the work was carried out, the stretch of the river involved was recovering from organic pollution, but a copper works discharge raised the copper content of the water to 1.0 mg^{L-1} and sometimes more. This was found to have a very striking effect on the ecology of the river; the benthic invertebrate fauna was completely eradicated and did not reappear in the next 11 river miles to the confluence with the Dove, where the copper content had fallen to

0.6 mg^{-1}. The algae were also seriously affected; above the works, glass slides suspended in the water for three weeks were colonized by several species characteristic of waters recovering from organic enrichment - Stigeoclonium, Nitzschia palea, Gomphonema parvulum, Chamaesiphon, and Cocconeis - and the total standing crop was approximately 1,000 cells mm^{-2}. Below the discharge, this number fell sharply to 150-200 cells mm^{-2}, and two unusual species, the small spherical Chlorococcum (Chlorophyceae) and the diatom Achnanthes affinis, made up most of the flora. This condition persisted for at least 3 miles, but 5 miles below the discharge the numbers rose steeply to over 33,000 cells mm^{-2}, and further downstream, and into the Dove some 30 miles below the discharge, total numbers of over 50,000 cells mm^{-2} were recorded. Although Chlorococcum and Achnanthes affinis persisted for much of this distance, the massive rise in numbers was also associated with the reappearance of the original algae - first Stigeoclonium and Chamaesiphon, then Gomphonema parvulum, Nitzschia palea, and finally, some 30 miles downstream of the discharge, Cocconeis.

More recently, Besch et al. (1972) have presented an extremely detailed account of the effects of acid mining wastes containing zinc and copper on the benthic diatom assemblages of the Northwest Miramichi River System, New Brunswick, Canada. The study involved both natural and artificial (plastic sheeting) substrata, and resulted in the recognition of a number of taxa apparently resistant to these metals. Whilst the diatom assemblages were found to be reliable indicators of average pH, it was stressed that the presence of metal pollution was not indicated by the mere presence of

particular taxa, but by the dominance of tolerant species coupled with the scarcity or absence of the less tolerant forms. It was further stressed that this information could only be used for surveillance purposes in the particular river system under study, and could not be applied to systems with different physico-chemical characteristics, or in the presence of other types of pollution.

Four outdoor artificial streams were employed by Williams and Mount (1965) over a period of 14 weeks to study the effects of zinc on periphyton assemblages growing on glass slides. The effect of adding 1.0 mg l^{-1} or more of zinc was to reduce the total number of species present and to increase the abundance of the remaining tolerant species. These tolerant species were however not considered to be true indicators of high levels of zinc - most were common algae likely to be encountered in a wide variety of habitats - and again it was the reduction in species diversity at high zinc levels that was considered by the authors to be of greater significance.

Whitton (1970b) performed laboratory experiments to study the effects of zinc, copper and lead on a large number of populations of green algae taken from flowing waters. Few relationships were found between resistance to one metal and that to another, suggesting that general statements about the metal resistance of particular taxa should be treated cautiously. However, a few tentative generalizations could be made: Microspora and Ulothrix tended to be resistant to all three metals, Oedogonium spp. tended to be relatively sensitive, and the Zygnemales (Mougeotia and Spirogyra) were largely intermediate in their resistance to

copper and lead, but showed a wide range of behaviour with regard to zinc, from relatively sensitive to very resistant. Cladophora glomerata was very sensitive to all three metals, whilst Stigeoclonium tenue was of intermediate resistance. The last named alga also provided the only evidence of natural variation in metal tolerance, with one population from a metal polluted stream showing a slight increase in its resistance to zinc.

So far the heavy metal tolerances of only a few algae have been studied both in the field and in the laboratory, but the two common and widely distributed lotic species mentioned above, Cladophora glomerata and Stigeoclonium tenue, have attracted considerable attention. In the case of Cladophora (Whitton, 1970a), all laboratory and some field studies indicate it to be one of the most sensitive of all the freshwater algae to the heavy metals studied, yet other apparently equally careful field studies do not seem to support this conclusion. Stigeoclonium, on the other hand, has generally been considered to be relatively tolerant of metal pollution, and it was suggested by Whitton (1970c) that a well illuminated flowing water site with abundant growths of Stigeoclonium tenue, but no Cladophora at all, should be treated as suspect for metal pollution. These statements were later contradicted to some extent by McLean (1974), who studied the field distribution of the two taxa at 169 river stations of widely varying water quality in South Wales. Equal (and comparatively low) tolerance to copper, lead and zinc was demonstrated by both algae, but Stigeoclonium showed greater tolerance than Cladophora to iron. It was suggested that the presence of Stigeoclonium combined with the absence of Cladophora at a site is essentially a

reflection of high levels of organic and nutrient enrichment, favourable to Stigeoclonium, but beyond the range of tolerance of Cladophora. It was further suggested that only under such optimum growth conditions can Stigeoclonium demonstrate its full tolerance to copper, lead and zinc; indeed, the field survey results indicated that in the absence of these conditions, lead and zinc at least would not be tolerated, although a tolerance to iron could apparently still be expressed. More recently, field and laboratory studies carried out by Harding and Whitton (1976) on the resistance of Stigeoclonium tenue to zinc, have shown that this species will in fact grow abundantly in zinc polluted waters (up to 20.0 mg l^{-1}, compared to only 0.53 mg l^{-1} in McLean's survey), and that at sites with mean zinc levels of about 0.2 mg l^{-1} and above, populations show increased resistance to zinc in comparison with populations from sites with lower zinc levels, this increased zinc resistance being largely, if not entirely, the result of genetic adaptation. Assays of populations from sites with high calcium levels suggested that these are less tolerant of a particular level of zinc than are populations from sites with low calcium levels, but the authors found no evidence to suggest that organic enrichment, or even simply the presence of high phosphate levels, are essential for the success of the species at sites carrying high levels of zinc.

As Whitton (1970c) observes, some of the anomalies apparent in the literature are no doubt associated with the effects of environmental factors on the toxicity of heavy metals. The possible effects of such factors in relation to the freshwater algae have apparently been little studied, although there is some

evidence to suggest that physical factors such as temperature and light, and chemical factors such as pH, hardness, salinity, and the presence of other metals, chelating agents, and algal extracellular metabolites, may be of significance in certain cases.

Although our knowledge of the toxic effects of substances other than metals is severely restricted, it does seem possible to draw some general conclusions about the effects of toxic pollution in the field (Hynes, 1960). After a poison enters a river, its concentration slowly declines, either because of dilution, precipitation or destruction. The numbers of algal species and individuals are at first usually markedly reduced, but the identity of the surviving dominants tends to vary from one situation to another, and no reliable indicators of toxic conditions seem to exist. With decreasing levels of toxicity, the flora is usually progressively restored, with a gradual reappearance of species and increase in numbers of individuals. In the absence of grazing pressure, population sizes may actually rise to very high levels, before eventually declining with the re-establishment of the invertebrate fauna.

(ii) Organic enrichment and eutrophication

These most important aspects of water quality are perhaps best considered against a more general ecological background.

In simple terms, the lotic ecosystem, like other ecosystems, consists essentially of three biotic components involved in the

cycling of inorganic and organic materials (Hawkes, 1977). Firstly, the producers - autotrophic organisms (mostly algae and higher plants), which are able to employ light energy to manufacture food from simple inorganic substances; secondly, the consumers - heterotrophic organisms (chiefly animals) which feed on the producers either directly, or indirectly via food chains; thirdly, the decomposers - mostly micro-organisms, assisted by scavenging animals, which use for food the organic material resulting from the waste products and death of all the organisms in the system. The activity of the decomposers results in the eventual stabilization and mineralization of the organic detritus, and this completes the cycling of material by making available plant nutrients for use by the producers.

A river is also an open ecosystem, constantly losing materials both to the sea and to the land, but at the same time gaining materials from the land. These materials may enter the stream either as organic matter, such as leaf-fall, or in the form of inorganic nutrient salts from land drainage. Thus, the natural lotic ecosystem is characterized by the presence and input of inorganic and organic materials, and by the presence of those organisms involved in the cycling of these materials, including the decomposers.

The self-regulating or homeostatic properties of the ecosystem enable it to readjust to changes, natural or anthropogenic, in environmental conditions, but there are limits to these capabilities, and if overburdened the whole ecosystem will collapse or its recovery may be unduly delayed. This point is relevant to the use

of rivers for the discharge of domestic and industrial effluents. The discharge of small amounts of sewage effluent into a stream providing an appreciable dilution factor may be regarded as a gain of material which would probably not have any serious effects, and in some cases may be beneficial. The discharge of larger quantities in situations having a limited dilution factor could result in greater imbalances in the ecosystem, and when these are detrimental to man's legitimate uses of the river, the condition may be regarded as pollutional. The potentially adverse effects arising from the discharge of biodegradable organic matter, such as sewage or the wastes from the processing of biological materials, are deoxygenation, increased levels of suspended solids, toxicity (partially oxidised sewage effluents may contain toxic levels of ammonia), and the growth of nuisance organisms such as sewage fungus. The increase in organic matter results in an increase in the decomposer component (indeed, it is the respiratory demand of the micro-organisms bringing about the oxidation of the waste that is largely responsible for the depletion of dissolved oxygen in the water), but as oxidation and stabilization proceed, a succession of biological assemblages appears, until an equilibrium is re-established. This is evidence of the homeostatic properties of the ecosystem.

In the past, because of ineffective treatment and overloaded plant, organic pollution was common in many of our rivers. Now, with more efficient treatment methods, it is technologically feasible and economically acceptable to oxidise most of our organic wastes before discharge. However, the resultant effluents still contain plant nutrients such as nitrates and phosphates, which in excessive amounts may induce an imbalance in the system

by encouraging the producer component, particularly the algae. In contrast to organic enrichment, this process may be regarded as inorganic enrichment or eutrophication, and again, if the effects are detrimental to legitimate use, the condition may be regarded as pollutional. A comprehensive discussion of the causes, effects and control of river eutrophication has been presented by Hawkes (1977). Along its course, a river gains nutrients naturally from the land and therefore becomes more eutrophic, but this natural eutrophication is supplemented by human activity, resulting in 'cultural eutrophication'. In the United Kingdom, most rivers are subject to some cultural eutrophication - even those receiving no point discharges receive nutrients from diffuse sources such as land drainage, in which nutrient concentrations are enhanced by modern agricultural practices. The adverse effects of increased algal productivity under eutrophic conditions have already been discussed in Section 1.2.2. Perhaps the single most important factor affecting 'in-river use' in many eutrophic rivers is the development of excessive growths of the attached filamentous green alga Cladophora - this problem is further discussed in greater detail in Section 6.1.

Comprehensive discussions of the biological effects of organic pollution in rivers have been presented by Hynes (1960) and by Hawkes (1962). There have been many biological studies of rivers polluted by a wide variety of organic effluents, and in general the effects seem to be broadly similar, although differences in detail may occur. In general, the algal component tends to be markedly reduced immediately below an organic discharge, but

is frequently replaced by conspicuous growths of the predominantly heterotrophic sewage fungus community. As recovery proceeds, and nutrient salts are released as a result of the mineralization of the organic matter, any sewage fungus disappears and the algal component is gradually restored; a few taxa, including Cladophora, may grow abundantly in this recovery zone before eventually declining as nutrient levels fall. This general pattern is now discussed in greater detail.

Sewage fungus is not a single organism, but a predominantly heterotrophic community of benthic micro-organisms typically forming slimy white, grey or brown plumose growths in rivers below sources of organic pollution. Much of our knowledge of the occurrence and composition of this community in the United Kingdom derives from work carried out by the Water Pollution Research Laboratory (now the Water Research Centre), and summarized by Curtis (1972). Most of the information is in fact based on a survey carried out during 1968-69, of 178 sites at which slime growths had been reported; the results of this survey are considered in detail by Curtis and Harrington (1971) and Curtis and Curds (1971). The typical members of the community (those most frequently occurring in significant numbers) are listed in Table 3.1. Most common were the filamentous sheathed bacterium Sphaerotilus natans, and zoogloeal bacteria of uncertain taxonomic status; compared with these two, all other types occurred only infrequently. A review of the biology of the more important sewage fungus organisms was presented by Curtis (1969). The most widely dominant slime organism, Sphaerotilus natans, appears to be favoured by moderate current velocities, moderate to high

TABLE 3.1 Typical Sewage Fungus Organisms (from Curtis (1972), based on a survey carried out in the United Kingdom, 1968-69).

(a) = percentage of sites at which the slime contained the species listed.

(b) = percentage of sites at which the slime contained large numbers (100 per ml) of the species listed.

		(a)	(b)
Bacteria	Sphaerotilus natans	88.9	50.3
	Zoogloeal bacteria	93.4	59.3
	Beggiatoa alba	29.6	5.6
	Flavobacterium sp.	36.9	1.7
Protozoa	Colpidium colpoda	37.3	26.1
	Chilodonella cucullulus	36.0	8.1
	Colpidium campylum	22.4	6.8
	Chilodonella uncinata	34.8	3.7
	Cinetochilum margaritaceum	31.1	5.0
	Trachellophyllum pusillum	32.9	5.0
	Paramecium trichium	28.0	4.3
	Uronema nigricans	20.5	4.3
	Hemiophrys fusidens	28.0	2.5
	Paramecium caudatum	28.0	2.5
	Glaucoma scintillans	23.6	3.7
	Carchesium polypinum	13.0	3.7
Fungi	Geotrichum candidum	7.3	4.5
	Leptomitus lacteus	3.9	3.3
Algae	Stigeoclonium tenue	9.5	2.8
	Navicula spp.	17.9	1.1
	Fragilaria spp.	11.3	0.6
	Synedra spp.	11.8	0

dissolved oxygen levels, and the simpler organic compounds (organic acids, alcohols and sugars) and organic nitrogen compounds (amino acids). In studies involving the use of laboratory recirculating channels (Curtis et al., 1971), Sphaerotilus - dominated slime formation was found to be proportional to the concentration of organic carbon above 1 mg l^{-1}.

In the 1968-69 survey, the outbreaks studied ranged from minor ones in effluent channels and small streams, to extensive growths in large rivers. Data collected at the time indicated that 73.5% of the outbreaks were less than 0.8 km in length, and a further 11% were 0.8-1.6 km in extent. In 99% of cases, the total length of watercourse affected was 8 km or less. Although sewage fungus outbreaks are therefore not extensive in British rivers, the localized effects can be serious, slime growths being unsightly, causing unpleasant odours when decomposing, and at times severely reducing stream oxygen levels to the detriment of fisheries. Other effects on fisheries include the prevention of spawning, the smothering of fish eggs and food organisms, and the fouling of nets and lines. The results of the survey strongly supported previous expectations that sewage fungus outbreaks are primarily associated with the presence of easily degradable organic substances, the most convenient overall measure of which is the 5 day BOD (Section 4.2). In the survey, sewage-fungus growths were always associated with the presence of a polluting discharge, causing marked deterioration in water quality, especially in terms of BOD, soluble organic carbon and suspended solids. The most frequent types of discharge were domestic sewage, industrial effluent, or a combination of both. The industrial effluents

most frequently involved were those from the food and drink industries, paper manufacture, and textile and dyeing processes, all of which contain biodegradable organic compounds. Domestic sewage effluents found the largest single group associated with sewage fungus outbreaks and there was a correlation between the amount of growth and quality of effluent both in terms of BOD and soluble organic carbon. Heavy outbreaks were largely associated with waters with BOD values in excess of 5 mg l^{-1} and organic carbon contents in excess of 6 mg l^{-1}. In waters with lower values, outbreaks were infrequent and mostly light. Outbreaks were also rare in waters with BOD and organic carbon contents greater than 30 mg l^{-1}, possibly because of the presence of toxic substances. It was concluded that in most cases, slime-promoting potential can be eliminated by adequate biological treatment of an effluent, and adequate dilution on discharge to the receiving watercourse.

The effects of organic pollution on the river benthic algal assemblages have been discussed in some detail by Hynes (1960). As this author points out, many of the data available from natural substrata tend to be essentially qualitative, whilst quantitative data are more often derived from studies involving the use of artificial substrata (e.g. Butcher, 1946, 1947). For this reason, it is difficult to present a balanced general account of the effects of organic pollution on these assemblages: quantitative data are certainly more appealing, but are in some respects of lesser ecological value than qualitative or semi-quantitative data derived from natural substrata (Section 3.1). A very broad general account can however be attempted.

Where organic pollution is so severe as to cause total deoxygenation, it results in the elimination of virtually all algae. If, however, some oxygen remains and a zone of sewage fungus is established below the discharge, total algal standing crop is at first markedly reduced. A number of taxa are however apparently resistant to these conditions, and may survive in small numbers in the sewage fungus zone. Curtis and Curds (1971) presented the following composite list of algal taxa from the WPRL sewage fungus survey: Stigeoclonium tenue, Cladophora glomerata, Ulothrix, Spirogyra, Vaucheria, Navicula, Fragilaria, Synedra, Surirella, Cymbella, Meridion, Melosira, Cymatopleura, Gomphonema, Diatoma, Amphora, Nitzschia, Oscillatoria, Phormidium, and Lyngbya. Of these, Stigeoclonium tenue (Chlorophyceae) was the most frequently encountered filamentous form, occurring at 9.5% of the sites and dominant at 2.8%. This alga is in fact widely considered to be tolerant of relatively high levels of organic pollution, but as McLean and Benson-Evans (1974) pointed out, it is actually found over a wide range of environmental conditions, especially during the spring growth phase, and can probably only be considered to be indicative of organic pollution when it grows abundantly and over a more extended time period. Abundant algal growth is in fact more characteristic of the zone below the sewage fungus, where the mineralization of the organic matter results in the release of inorganic nutrients to the water. In addition to Stigeoclonium, a number of other algae are frequently reported in large numbers from this transition zone - the most characteristic are perhaps the diatoms Nitzschia palea and Gomphonema parvulum (Butcher, 1946, 1947; Evans and Marcan, 1976). As recovery proceeds, these forms tend to diminish in importance and are joined by others as a progressive

restoration of the flora takes place. Total algal standing crop may however remain high under these eutrophic conditions, with the filamentous green alga Cladophora (Section 6) probably forming a further distinct zone before eventually declining as a result of the depletion and dilution of nutrients.

Although these changes are evidence of the homeostatic properties of the river ecosystem, it is unlikely that any river receiving substantial quantities of organic matter, and therefore with an extended recovery zone, would eventually revert to its original condition upstream of the discharge. Any tendency to do so is usually masked by other longitudinal changes - natural changes in physical and chemical characteristics, and natural and cultural eutrophication from land drainage. The pattern of recovery may also of course be abruptly truncated by the entry of another point discharge, or by confluence with another watercourse.

Since individual rivers and effluents are so variable in character (many sewage works effluents contain toxic substances of industrial origin as well as organic matter), the precise details of the effects of particular discharges also tend to vary. This point is well illustrated by the work of Benson-Evans et al. (1975) on the river Ebbw Fawr, South Wales. They were able to recognise a series of twelve well defined recovery stages, based on the dominant benthic sewage fungus organisms and algae, below a steelworks discharge. This scheme was designed to indicate improvements in water quality both spatially, downstream of the discharge, and temporally, as effluent treatment became more effective, and it correlated significantly with selected physico-chemical parameters.

The authors stressed, however, that the system would be too sensitive for more general application.

3.2.2 Applications

In Section 1.2.3 the biological indicator concept, as applied to fresh waters, was defined broadly to include bioassay and bioaccumulation as well as biological surveillance (meaning the detection of significant field changes in community composition and structure). In the present section, all three areas are considered in greater detail, with special reference to the river benthic algae.

3.2.2.1 Bioassay

Bioassay techniques employing algae have been used extensively to assess the algal growth promoting potential or toxicity of various water types. The most usual approach is to estimate algal growth in the test water under standard conditions and over a given period of time. Planktonic algae tend to be the first choice for this type of work, presumably because they are considered to be of greater economic importance than the benthic forms (Section 1.2.2) and because the appropriate laboratory techniques are better developed. Thus most river water bioassays (Whitton 1975, 1979) have employed planktonic algae in tests very similar to those originally developed for lentic waters, and this would seem entirely justifiable, especially if the test is being performed to assess potential suitability for potable supply.

A number of attempts have however been made to develop more specialized bioassays involving the use of river benthic algae. Trotter and Hendricks (1976 a, b) developed a continuous flow

system incorporating glass slides supporting growths of the filamentous green alga Stigeoclonium subsecundum. The toxicity of intermittent chlorination was investigated using this system (Trotter et al., 1978) and was found to be related to the algal biomass at the beginning of the bioassay. The term 'minimal resistant biomass' was used to describe the lowest biomass of the alga able to survive and continue to grow, when subjected to a specific level of chlorine, added over a period of 30 minutes, at intervals of 6 hours for a period of one week. This ability to survive was apparently also related to changes in the morphology of the algal mat.

Lin (1977) developed a technique for the isolation and laboratory culture of the benthic diatom Navicula seminulum var. hustedtii, involving growth on a solidified agar substratum in continuous flow culture. The system was used to assay the effect of an algicide, copper triethanolamine. In a 14 day experiment, the presence of 3 mg^{-1} algicide reduced the growth of the diatom to approximately one-tenth of that in the control, and resulted in a severe reduction in chlorophyll a concentration.

There is now a considerable body of literature concerning the use of artificial streams for experimental research in lotic ecology (Warren and Davis, 1971; McIntire, 1975) and it would seem logical to employ such systems for bioassay purposes also. The laboratory streams described by Gerhart et al.,(1977) of the University of Minnesota at Duluth were developed specifically for bioassay work. Five identical but independent streams, constructed entirely of plastics, are fed with water taken directly

from Lake Superior. Each stream is also provided with a separate inflow for the introduction of nutrients or toxicants. The authors report the results of a preliminary experiment to test the effects of low levels of coal leachate on periphyton assemblages attached to artificial substrata (horizontal plates of unglazed porcelain) placed in the streams. The results are presented in terms of ash-free dry weight, chlorophyll a concentration and community composition and structure. Three streams were maintained as controls, but in the 25 day time period employed, there appeared to be very few significant differences between these and the two treated streams.

Although in most algal bioassays the results are reported in terms of some expression of algal growth, other responses may be of value. Rizet et al., (1978), for example, have described a technique based on the observed morphological deformation of diatom (Synedra ulna) frustules in the presence of metal ions and other pollutants.

The possibility of using the filamentous green alga Cladophora for routine river water bioassay does not seem to have been explored, although such a technique would be of potential value because of the nuisance caused by excessive development of this organism in eutrophic waters. A more detailed review is presented in Section 6, together with the results of some preliminary river water bioassay studies.

In Section 1.2.3 it was noted that the observation in the field of well defined biological responses at the organism level

(for example the use of captive fish to provide a rapid early warning of environmental deterioration) was essentially an extension of the bioassay approach. A number of possibilities exist for the use of algae in an analogous way, either by conducting bioassays in the field, or by the laboratory study of certain morphological or physiological features of algae recently removed from the field. Whitton (1979) refers to heterocyst formation, polyphosphate granule formation, hair formation, morphological deformation, genetic resistance to pollutants, and various metabolic activities such as nitrogen fixation, enzyme activity and electron transport activity, all of which may be indicative of specific environmental conditions. Most of these approaches are however poorly developed and not sufficiently well validated for general application in lotic waters.

3.2.2.2 Bioaccumulation

Many studies have shown that aquatic algae are capable of accumulating important pollutants such as heavy metals, radioisotopes and synthetic organic biocides, to produce an internal concentration much greater than in the aqueous environment (Whitton and Say, 1975; Whitton, 1979). Quantitative information concerning such accumulation has been obtained both by direct analysis and by uptake experiments, but in the case of flowing waters the two techniques have seldom been used simultaneously. The data in the literature are presented in a variety of ways, so it is not always easy to compare results. The most usual index of accumulation however, is the ratio of the substance in the organism (dry weight) to its level in the surrounding water, measured in equivalent units

(e.g. $\mu g.g^{-1}$ to $\mu g.ml^{-1}$). This figure is variously referred to as the Enrichment, Concentration or Storage Ratio (or Coefficient or Factor).

The review presented by Phillips (1977), although concerned primarily with the bioaccumulation of metals in marine and estuarine environments, contains much valuable general information. Of particular interest is the list of characteristics considered to be desirable of the organisms chosen as indicators of the environmental levels of accumulated pollutants. The most important of these in relation to fresh-water algae can be stated as follows: the organism should be 'sedentary', abundant in the study region, tolerant of a wide range of physico-chemical conditions, reasonably large (yielding adequate tissue for analysis), easy to sample, able to survive under laboratory conditions (allowing further study), able to accumulate the pollutant without being killed by the levels encountered, and the concentration factor should be relatively high (allowing direct analysis without pre-concentration) and constant at all the localities studied and under all the conditions encountered.

It must be admitted that in many studies not all of these criteria can be said to have been adequately investigated, and indeed a number of studies have indicated serious problems. In particular, it seems that the bioaccumulation process may be affected significantly by environmental factors. In the study of Harvey and Patrick (1967), direct comparison was made of concentration by algae growing under continuous flow conditions with ones grown in batch culture. Differences were found in the

concentration of CS-137 by filamentous blue-green algae, filamentous green algae and unicellular diatoms grown under both types of condition. However the enrichment ratios were generally higher by a factor of two in batch tests than in continuous flow tests. Among the three green algae studied, continuous flow tests indicated little difference in their ability to accumulate Zn-65, Sr-85 and Cs-137, but the average enrichment ratios for the three radionuclides did differ considerably: 3800, 230 and 460 respectively. All of the radionuclides were desorbed rapidly when the algae were transferred to non-radioactive media, and at least in the case of Cs-137, desorption occurred more rapidly in continuous flow than in batch culture. Colemen et al., (1971) used three algal species - Chlorella vulgaris, Euglena viridis and Pediastrum tetras - to study the bioaccumulation and toxicity of cobalt and zinc. With both metals, an increase in environmental concentrations led to increased uptake by the algae, while at the same time there was generally an overall decrease in growth. Cushing and Rose (1970) described the use of a laboratory closed lotic 'microcosm' to study the uptake of Zn-65 by Columbia River periphyton. The apparatus consisted of two identical glass tubular chambers connected in series, the first tube supporting a periphyton community derived from the river (and dominated by the algal genera Ulothrix, Gomphonema, Melosira, Navicula and Achnanthes), and the second tube free of algae. Each tube was fitted with a detector-photomultiplier assembly such that the first detector registered the radioactivity in the periphyton and the surrounding water, and the second detector the radioactivity in the water only. Uptake of Zn-65 was considerable under a number of different light regimes, and by killed communities, suggesting an

adsorptive uptake process. Uptake was proportional to initial ambient concentration, which decreased during the course of the experiments. Increasing the concentration of stable zinc or magnesium proportionately decreased the uptake of Zn-65, suggesting a competition for binding sites and supporting the adsorptive uptake hypothesis. It was noted that there were many similarities in the uptake pattern between this heterogeneous periphyton assemblage and unialgal cultures or single species of plants.

In a field study conducted by Harding and Whitton (1978), a logarithmic plot of zinc in the terminal 2 cm tips of the red alga Lemanea fluviatilis, against zinc in the surrounding water, showed a linear relationship over the range 0.01-1.0 mg Zn l^{-1}. There was no such clear correlation for lead, however. The field results reported by Keeney et al., (1976) and by Whitton (1979) suggest that Cladophora may prove to be a valuable bioaccumulation indicator for metals in both lentic and lotic habitats; this possibility is explored further in Section 6, which also contains a more detailed literature review.

Cladophora has also been reported to accumulate the biocide DDT (Woodwell, 1967; Ware et al., 1968) and, together with the filamentous green alga Spirogyra, has been included in studies of the uptake of various radioisotopes (Kulikova, 1960). Cushing (1967) included periphyton among the bioaccumulation indicators of radionuclide levels downstream of nuclear reactors. Studies were carried out on periphyton assemblages growing on glass slides in the Columbia River. The uptake of P-32 and Zn-65 correlated well with dry weight and ash weight, but not with ash-free dry weight

(i.e. organic weight) or with environmental levels, again suggesting an adsorptive uptake process.

3.2.2.3 Biological Surveillance: Data Analysis

Any river biological surveillance programme will involve three basic stages: sample collection, sample analysis and data analysis. The first two of these have already been discussed in Section 3.1, so the present section is concerned primarily with data analysis. Data analysis itself involves several elements, including the processing, if any, of the basic survey data, and the presentation and interpretation of results. The basic data can of course be presented directly, either as a written report, or in the form of tables, graphs or diagrams, as a preliminary step to interpretation. This is the case with many conventional ecological surveys, whether or not they were undertaken to study the effects of changes in water quality. It is of course surveys such as this, together with laboratory studies, that provide the ecological basis discussed in Section 3.2.1 that is essential to the valid interpretation of further biological surveillance data.

In large scale biological surveillance programmes, however, it is often impractical to use all the basic data directly, and in any case significant information may not be immediately apparent. It therefore becomes desirable to reduce or to condense the bulk of the survey data and to present the results as clearly and concisely as possible. Most of the important data processing techniques have been reviewed by Warren (1971), Wilhm (1975) and Hellawell (1978).

Basic data may first be subjected to some form of essentially objective processing procedure, again as a preliminary step to interpretation. Thus, the various comparative methods (involving the determination of measures of similarity or association between different stations), ranking methods, and graphic methods (including techniques such as recurrent group analysis, cluster analysis, minimum spanning trees and control charts) discussed by Hellawell (1978), are designed essentially to aid the recognition of trends which may be significant in relation to water quality. The actual interpretation of the results of such data handling techniques must however be carried out separately and with care, taking into account the properties of the techniques employed and usually referring back to the original data. Techniques such as these seem to be gaining in popularity, especially as the appropriate computing facilities become more widely accessible. Kaesler and Cairns (1972) performed cluster analyses on biological data collected from the Upper Potomac River, to assess the effect of a power station discharge. Briefly, the technique involves the computation of a matrix of similarity coefficients in such a way that each station in the survey is compared directly with each of the others. This matrix is then processed systematically and displayed graphically in the form of a 'dendrogram' in which stations are linked together hierarchically, those showing the greatest affinities tending to form distinct groups or clusters. The aquatic insects and, to a lesser extent, the diatoms exhibited clustering patterns that were apparently representative of the total biota, and it was suggested that the study of these two groups and the exclusion of other algae, protozoa, other invertebrates and fish would significantly reduce the cost of such surveys without appreciably affecting their

information value.

Allen and Skagen (1973) discuss the use of multivariate analysis as an approach to the study of algal communities. This involves the ordered distribution of data points (e.g. taxa, stations or environmental variables) in multidimensional space, followed by the search for axes strategically placed within this abstract hypervolume such that possible trends become apparent with the minimum loss of information. This technique has been used extensively by Descy (1973, 1976 a, b, c) to study the diatom assemblages of polluted European rivers such as the Meuse and the Sambre. This worker was apparently also able to use the technique to make a relatively objective assessment of the indicator value of individual taxa within these systems; this was then used to calculate an index of water quality for each station.

A number of other workers have attempted to develop data processing techniques based on one or more of the community responses listed in Section 1.2.3 as being of known indicator value. Such techniques would be expected to identify more specifically any trends contained within the basic data that are significant in relation to water quality. Under this heading can be included the various measures of community diversity and the various pollution classification systems, grades, indexes and scores by which single stations can be described, or assigned a label or value intended to be inherently indicative of water quality. Several such systems have been based partly or wholly on algal data; the most important of these are now discussed.

(i) Evaluations of species diversity

The literature on species diversity is extensive and complex. A concise introduction to the subject has been presented by Odum (1971), whilst Hellawell (1978) has reviewed the important concepts, models and applications in relation to river biological surveillance.

Of the total number of species in a sample, only a few are typically represented by large numbers of individuals, the majority being represented by relatively few individuals. Ecological stress, such as might be caused by pollution, tends to result in a reduction in species diversity, that is, a reduction in the total number of species present coupled with an exaggerated increase in the quantitative importance of a few of these species. A number of attempts have been made to assess water quality changes in terms of algal species diversity.

Patrick et al., (1954) applied Preston's (1948) lognormal model of community structure to the diatom assemblages growing on glass slides suspended in floating Catherwood Diatometers (Section 3.1.2). Diatom samples were analysed and the results expressed by plotting on graphs the numbers of species in successive geometric intervals of abundance. The effect of pollutional stress was to alter the shape of these curves. A number of problems were apparent, however; the shape and stability of the curves is apparently also influenced by immersion time and by sample size, necessitating the counting of large numbers of individuals. Yount (1956) used the method to study diatom assemblages from the

unpolluted Silver Springs, Florida, and obtained curves that were suggestive of polluted conditions. Yount's original material was later re-examined by Hohn (1961), who explained this apparent conflict in terms of differences in water hardness between the different sites used in the two studies. Shortly afterwards, Patrick and Strawbridge (1963) proposed a statistical method for determining the extent of such possible natural variation, and expressed a hope that further studies would help to improve the sensitivity of the method to different types and degrees of pollution. The method has in fact continued to be strongly advocated by Patrick and her colleagues (Hohn, 1966; Patrick, 1973), although apparently not widely employed by other workers (Bartsch and Ingram, 1966).

In contrast to this graphic approach, most other measures of species diversity have involved the calculation of numerical diversity indexes. Some simple indexes relate only the number of species present (S) to the total number of individuals (N), e.g.

$I = S - 1/\log_e N$ (Margalef, 1951)

and $I = S/\sqrt{N}$ (Menhinick, 1964)

These indexes do not take into account the quantitative importance of each species (and are therefore insensitive to changes in community structure involving changes in the relative quantitative importance of species), and are also influenced by sample size. Of more value are the indexes derived from 'information theory' (Wilhm and Dorris, 1968). Diversity is equated with the uncertainty regarding the identity of an

individual taken at random from a community. The more species that are present in a community, and the more equal their abundance, the greater the uncertainty and hence the greater the diversity. The value of species diversity, $\bar{d}$, is claimed to be relatively independent of sample size and can be calculated from:

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

where n = the total number of individuals in the sample
and n_i = the number of individuals of the i^{th} species

In this way, two components of species diversity are recognised: the index varies both with the number of species ('species richness') and the proportional distribution of species ('equitability') in the sample. The index will be maximal, for a given number of species, when all are equally represented. It is important to recognise this since the quotation of a diversity index alone is ambiguous: for any given value the community may have a range of structures from high species richness with low equitability, to low species richness with high equitability. Although it is possible to take this problem into account (Hellawell, 1978), the basic assumption that high diversity should be associated with high species equitability seems to be ecologically unsound, since in most natural communities there are marked differences in population sizes (Hawkes, 1979). It is appropriate to note at this point that the graphic method of Patrick et al., (1954) discussed above does not make this assumption. Pielou (1969) has further suggested that taxonomic considerations should also influence the interpretation of species diversity indexes. Two communities may have the same

index and equitability, but one may consist of several different species of the same genus, whilst in the other all the species might belong to different genera; in this case, the latter should perhaps be regarded as the more diverse community.

The Sequential Comparison Index (Cairns et al., 1968) is essentially a simple diversity index derived from sample examination. Consecutive individuals, taken at random from a sample, are compared and a note made of the number of times a difference is observed between each individual and its immediate predecessor. Each sequence of consecutive identicial individuals constitutes a 'run', the index then being calculated as:

SCI = number of runs/total number of individuals

The method is said to have the advantage that no taxonomic expertise is required, since the worker simply has to record differences between consecutive individuals. This is in fact debatable, since many common species of algae are capable of presenting strikingly different morphological aspects according to their orientation in relation to the observer, and conversely, certain distinct species may appear to the uninitiated to be very similar. On the other hand, the SCI is probably more readily applied to algal than to invertebrate samples, since rapid and unbiased counts can be performed simply by scanning microtransects of the preparation. In a later publication (Cairns and Dickson, 1971) the SCI was refined in an attempt to make it statistically more reliable and ecologically more valid. Methods were described for determining the optimum number of individuals to be counted,

and the number of replicate determinations of the index to be made on the same sample. The index was also weighted by multiplying by the number of different taxa present, thereby taking species richness into account. The process of refinement was carried further by Keefe and Bergersen (1977), who proposed a method incorporating the factor n_i/n, as in the more advanced indexes. This method requires the investigator to sort the sample into groups of similar taxa, however, and is therefore probably less suited to the analysis of algal samples than to invertebrate samples.

Archibald (1972), working on benthic diatom samples, compared the performance of several different diversity indexes. The SCI was found to be the simplest in application, and as effective as the other indexes in estimating species diversity, but the study further suggested that in many cases diatom diversity does not correlate well with water quality. It was suggested that only relatively high species diversity is significant, being indicative of high quality water, but that since ecological factors other than pollutional stress can apparently result in a lowering of species diversity, moderate and low diversity values are likely to be encountered from virtually any water quality, and are consequently of little value. The results of benthic algal surveys reported in the literature are apparently conflicting: Benson-Evans et al., (1975), for example, found significant correlations between diversity indexes and physico-chemical conditions whilst Hodgkiss and Kan (1978) and Wilhm et al., (1978) found no such clear relationship.

Hughes (1978), working on benthic invertebrate samples from the river Cynon, South Wales, found that factors such as the sampling method, the area sampled, the time of year and the taxonomic level of identification all influenced the value of the information theory diversity index to some extent. It seems reasonable to suppose that these factors should also be taken into account when working with the benthic algae.

Quite apart from these problems, however, most authorities would agree that a major disadvantage of all diversity indexes is that they can not take into account the identity, and therefore the possible indicator value of particular taxa.

(ii) The Saprobien system

The literature on the Saprobien system is again extensive and complex. Sladecek (1973) has presented the most recent comprehensive review, which also incorporates a detailed exposition of his own work in this field.

In general terms, the system is based on the premise that different waters can be classified according to the type and degree of pollution present, and that different indicator taxa (usually species) are associated with these different physico-chemical classes. Although the origins of the system can be traced back to the mid-nineteenth century, the first reasonably coherent statement came at the beginning of the present century, with the publication by the two German workers Kolkwitz and Marsson (1908, 1909) of extensive lists of indicator taxa. At this time, the

system was confined to organically polluted waters; rivers were zoned according to the degree of mineralisation of organic matter, and four basic zones were recognised:

Polysaprobic	- Grossly polluted; organic compounds complex.
Alpha-mesosaprobic	- Polluted; organic matter partly degraded.
Beta-mesosaprobic	- Mildly polluted; degradation near completion.
Oligosaprobic	- Organic matter completely mineralised.

The lists of indicator taxa associated with each zone have been revised a number of times (e.g. Kolkwitz, 1935, 1950; Liebmann, 1962; Sladecek, 1973) to take account of new research developments, although the work of these and other authors has inevitably resulted in some confusion and inconsistency as to the indicator value of particular taxa.

The Saprobien system has at times been severely criticized (see Sladecek, 1965, 1973), mainly on account of its apparent subjectivity and simplistic reliance on the indicator species concept, namely that the presence of a particular species or group of species is always indicative of a particular set of environmental conditions. A number of attempts have therefore been made to strengthen the ecological validity of the system. Fjerdingstad (1964, 1965) for example, whilst retaining the essentially descriptive character of the system, recognised that many algal species are in reality found over a relatively wide range of environmental conditions, and that the composition and structure of the whole assemblage or community should if possible be taken into consideration. Other workers (cited by Bick, 1963;

Sladecek, 1973 and Hellawell, 1978) have developed numerical indexes based on the system, but often taking into account the relative quantitative importance of taxa, and adopting a more flexible approach to the problem of indicator value. Attempts have also been made (Sladecek, 1973) to extend the system to cover the entire range of different water and pollution types, although the resulting complexity tends to be rather confusing, and, it could be argued, counter-productive to the desire for more general acceptance.

The Saprobien system remains popular in Europe (Bick, 1963) but does not seem to have been applied extensively in Great Britain, or the United States of America (Bartsch and Ingram, 1966). Benson-Evans et al., (1975), working on the benthic algal assemblages of polluted rivers in South Wales, found the system to be relatively insensitive, with all the sites studied falling into either the alpha- or beta-mesosaprobic categories. Apparently, many of the organisms and assemblages found in these Welsh rivers are not mentioned in the Saprobien system literature, and it was further thought that the types of pollution encountered in the South Wales region - including industrial discharges from the coal and steel industries - were not adequately accommodated by the system, which was developed primarily for organic enrichment.

It seems regrettable that the Saprobien system has not been employed more widely, especially since much serious work has been carried out by the continental workers, and the literature is now very large. On the other hand, there would seem to be a number of practical and ecological problems involved in applying

the system to British rivers, and the prospect has perhaps become somewhat formidable.

(iii) The Palmer Index

Palmer (1969) compiled information on algae tolerant of organic pollution from the published reports of 165 authors, and then proceeded to construct two lists, one of genera and the other of species, in which the taxa were arranged in order of supposed decreasing tolerance. The first twenty taxa from each list were then given a relative pollution index factor (5 for the most tolerant forms, down to 1 for the least tolerant). In the analysis of a sample, any of the twenty genera or species that are encountered are recorded and their pollution index factors totalled. A score of 20 or more for a sample is taken as evidence of high organic pollution, whilst a score of 15 to 19 is taken as probable evidence of high organic pollution. Lower figures would indicate low organic pollution, that a sample was not representative, or that some other factor interfering with algal persistence was present and active.

Although extremely simple, the Palmer Index is clearly rather subjective, and does not in any case seem to have been employed widely in its original form. Benson-Evans et al., (1975) found it necessary to employ a considerably modified version: the lists of taxa were altered to comply with the local Welsh flora, and the pollution index factors were reversed (i.e. Palmer's 5 would become 1, and 4 would become 2, etc.). This overcame the tendency of the original index to be self-compensating, as a result of

polluted sites (supporting a small number of high-scoring tolerant taxa) giving totals similar to less polluted sites (supporting a larger number of low-scoring less tolerant taxa). Both the original Palmer Index and the Benson-Evans modification are presented in Table 3.2.

Hodgkiss and Kan (1978), working on epilithic algae from streams in the New Territories, Hong Kong, proposed a further modification of the Palmer Index. This was based on Palmer's original list of 80 pollution tolerant species of algae, and also took into account the relative quantitative importance of the different species. This modification also resulted in an improvement in the performance of the index, and the authors considered that further improvement might result from the alteration of the species list, as described above, to reflect more clearly the composition of the local flora.

(iv) Ecological Spectral Analysis

Lowe (1974) compiled data on the environmental requirements and pollution tolerance of 300 common species and varieties of fresh water diatoms, based on 48 references. The following parameters were considered: current, temperature, pH, salinity, nutrient status, organic pollution (Saprobien system), habitat and geographical distribution. A consensus of opinions for each parameter was established for most taxa, and it was suggested that this compilation be employed to evaluate data from plankton and periphyton samples collected for the assessment of water quality.

TABLE 3.2

a) The Palmer Index (Palmer, 1969)

Genus List	Rating	Species List	Rating
Anacystis	1	Ankistrodesmus falcatus	3
Ankistrodesmus	2	Arthrospira jenneri	2
Chlamydomonas	4	Chlorella vulgaris	2
Chlorella	3	Cyclotella meneghiniana	2
Closterium	1	Euglena gracilis	1
Cyclotella	1	Euglena viridis	6
Euglena	5	Gomphonema parvulum	1
Gomphonema	1	Melosira varians	2
Lepocinclis	1	Navicula cryptocephala	1
Melosira	1	Nitzschia acicularis	1
Micractinium	1	Nitzschia palea	5
Navicula	3	Oscillatoria chlorina	2
Nitzschia	3	Oscillatoria limosa	4
Oscillatoria	5	Oscillatoria princeps	1
Pandorina	1	Oscillatoria putrida	1
Phacus	2	Oscillatoria tenuis	4
Phormidium	1	Pandorina morum	3
Scenedesmus	4	Scenedesmus quadricauda	4
Stigeoclonium	2	Stigeoclonium tenue	3
Synedra	2	Synedra ulna	3

TABLE 3.2 (continued)

b) Modified Palmer Index (Benson-Evans et al., 1975).

Genus List	Rating	Reversed Rating	Species List	Rating
Sewage Fungus	5	1	Sewage Fungus	5
Oscillatoria	5	1	Nitzschia palea	5
Euglena	5	1	Navicula minima var. atomoides	5
Scenedesmus	4	2	Oscillatoria limosa	4
Chlorella	3	3	Stigeoclonium tenue	4
Navicula	3	3	Navicula viridula var avenacea	3
Nitzschia	3	3	Diatoma vulgare	3
Stigeoclonium	2	4	Surirella ovata	3
Synedra	2	4	Synedra ulna	3
Ulothrix	1	5	Gomphonema parvulum	3
Surirella	1	5	Hantzschia amphioxys	3
Spirogyra	1	5	Cladophora glomerata	2
Closterium	1	5	Cocconeis placentula	2
Cladophora	1	5	Cymatopleura solea	2
Gomphonema	1	5	Fragilaria capucina	2
Hantzschia	1	5	Closterium turgidum	2
Melosira	1	5	Navicula cryptocephala	1
Diatoma	1	5	Navicula rhynchocephala	1
Chlorococcum	1	5	Navicula gregaria	1
Phormidium	1	5	Melosira varians	1
Asterionella	1	5		
Cocconeis	1	5		
Stauroneis	1	5		
Achnanthes	1	5		
Cymbella	1	5		

Information of this type has in fact been employed on a formal basis by Vanlandingham (1976) in a study of the algal plankton assemblages of the St. Joseph River, Michigan and Indiana. For each sample, a standard data sheet was completed in such a way that it was possible to see, at a glance, the proportion of species present that had been reported elsewhere from particular environmental conditions. The parameters chosen were current, pH, salinity, nutrient status, saprobity and habitat. In this way, a comprehensive profile of the station emerges - it may, for example, be seen to be characterized by a predominance of periphytic organisms, mostly indifferent to current velocity and salinity, but commonly associated with alkaline, eutrophic and beta-mesosaprobic waters.

This approach, known as Microalgal Spectral Analysis, has apparently been used in palaeoecological work, but could presumably be applied more widely for water quality surveillance purposes. It could be said that it is essentially a return to the descriptive and interpretive approach, but it is interesting to note that attempts are now being made to synthesize ecological information concerning the algae into an organised and accessible form. More recently, Whitton (1979) has indicated the desirability of some form of computer-based data storage and retrieval system, but also pointed out the difficulties involved, particularly in the development of a reliable taxonomic coding system.

(v) Other approaches

A few attempts have been made to use biomass and productivity data in the assessment of water quality. Weber and

McFarland (1969) proposed the following index of water quality:

$$I = \frac{\text{ash-free weight of periphyton (g m}^{-2})}{\text{chlorophyll } \underline{a} \text{ (g m}^{-2})}$$

They reasoned that values of I in unpolluted waters would be based mostly on populations of algae, and would therefore be lower than in polluted waters supporting larger populations of bacteria and other heterotrophs. Although the data of these authors supported this interpretation, a further study by Cooper (1972) was less conclusive, indicating no significant differences between stations at various distances below a polluting discharge.

The ratio of phaeophytin (degraded chlorophyll) to chlorophyll has been used in various river studies to indicate water quality. Garcia (1970) found the ratio to be higher in both the water column and the sediments at four polysaprobic sites than at four mesosaprobic sites. Cooper (1972), however, again working on the periphyton assemblages at various stations downstream of a polluting discharge, found little spatial or temporal variation in the value of this index.

Tilley and Haushild (1975) used glass slides to estimate periphyton productivity in the Duwamish-Green River system (Washington), and attempted to correlate the results with water quality. The average net primary productivity of the attached algae increased five-fold in the downstream direction, varying directly with increases in selected nutrients, but inversely with stream gradient. This indicates the difficulties involved in the

interpretation of such data, and the need to take factors other than water quality into consideration.

In conclusion, it can be said that whilst most data analysis procedures inevitably result in some loss of information, the process of condensation may lead to new insights, and an overall gain in comprehension, particularly by the non-biologist. As Hellawell (1978) warns, however, it is important when applying data analysis techniques to understand their properties and limitations. Many indexes are based on essentially subjective or arbitrary assessments of the indicator value and abundance of particular taxa. It is often possible for identical values to be derived from entirely different sets of original data, the range of possible values may be limited and the scale may not exhibit equal sensitivity over this range. It must also be remembered that most indexes are essentially descriptive, and should not be subjected to conventional parametric statistical analysis.

Ideally, then, surveillance data should be interpreted by an appropriately trained biologist, with first hand knowledge and experience of the sampling sites under consideration, and the methods of sample collection and analysis, and data processing, employed.

4. PRELIMINARY STUDIES ON SAMPLING METHODOLOGY (PHASE 1)

4.1 Objectives

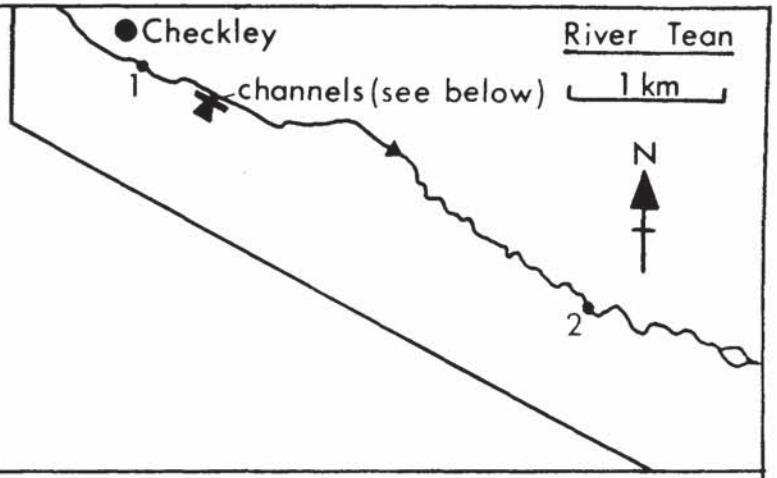
The objectives of Phase 1 (see Section 2.1) were to select sampling methods suitable for routine use in all types of river, by studying the assemblages growing on natural and selected artificial substrata, both in 'riffles' (shallow stretches with the water flowing rapidly over a predominantly stony substratum) and 'pools' (deeper reaches with slow current velocity and variable substratum type), and in a range of different water qualities.

4.2 The Sampling Stations

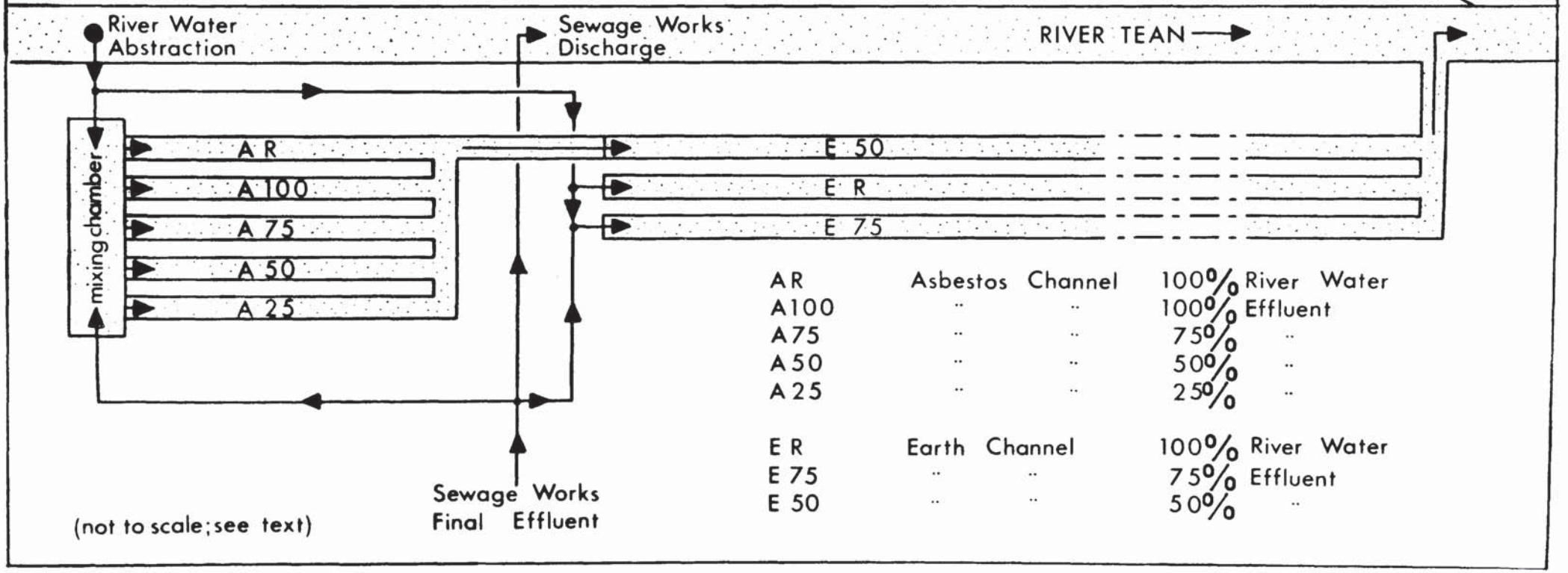
All Phase 1 investigations were based at the Hydrobiological Field Station at Checkley, Staffordshire. This field station was established jointly, on a separate research contract, by the Applied Hydrobiology Section of the University of Aston, and the Water Research Centre; permission was obtained to make use of the facilities there.

At the time of the investigations (1976), the field station consisted essentially of two series of outdoor artificial channels - five asbestos-concrete channels and three earth channels - integrated with the Blithe Valley Water Reclamation Works at Checkley (Figure 4.1). The bulk of the works' effluent was discharged directly to the river Tean (Section 6.2.2), but by diverting a proportion of this effluent before discharge, and

FIGURE 4.1 Map to show position of river Tean stations 1 and 2 with schematic representation of the artificial channels at Checkley (1976)



Arrows indicate direction of flow



AR	Asbestos	Channel	100% River Water
A100	"	"	100% Effluent
A75	"	"	75% "
A50	"	"	50% "
A25	"	"	25% "
E R	Earth	Channel	100% River Water
E 75	"	"	75% Effluent
E 50	"	"	50% "

mixing it with river water abstracted directly from the Tean upstream of the main discharge point, it was possible to obtain within the channel systems a series of different water qualities.

The asbestos channels were each 50 m in length, 30 cm wide and 20 cm deep, and set at a gradient of 1 in 200. They were fed from a mixing chamber to provide five different water qualities - 100% effluent (A100), 75% effluent (A75), 50% effluent (A50), 25% effluent (A25) and 100% river water (AR). The flow in each asbestos channel was 0.01 m^3 sec^{-1}, and current velocities were in the range 30-45 cm sec^{-1}. The three earth channels were each 300 m in length, and each was constructed to provide an alternating riffle-pool system: firstly a 90 m riffle stretch, then a 60 m pool stretch, followed by a further riffle and pool of the same dimensions. The riffles were 1 m wide and 15 cm deep with a gravel substratum set at a gradient of 1 in 200, providing a current velocity of 43 cm sec^{-1}. The pools were 1.4 m wide and 45 cm deep with a level muddy substratum and current velocity of 10 cm sec^{-1}. The three water qualities were 75% effluent (E75), 50% effluent (E50) and 100% river water (ER). The combined effluent from the five asbestos channels formed the feed to the E50 earth channel, but the E75 and ER channels were fed independently. The flow in each earth channel was 0.05 m^3 sec^{-1}, and the combined effluent from both the channel systems was discharged to the river Tean downstream of the main works' discharge. In the Phase 1 investigations, only the second (downstream) riffle sections of the earth channels were employed.

In addition to the artificial channels, two river stations

were chosen on the Tean itself, upstream and downstream of the sewage works and channel system discharges. Station 1, at Checkley (National Grid Reference SK 028376) was approximately 0.5 km upstream of the main discharge, and here a riffle (T1R) and a pool (T1P) were selected for study. Station 2, at Beamhurst (SK 059361) was approximately 4 km downstream of the discharge, and again a riffle (T2R) and a pool (T2P) were selected for investigation. The pools were 1-1.5 m in depth.

4.3 Materials and Methods

4.3.1 Physico-chemical

The following physico-chemical determinations were carried out: current velocity, temperature, suspended solids (SS), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chloride, alkalinity, hardness (calcium and magnesium), ammoniacal nitrogen (NH_3-N), oxidised nitrogen (NO_3-N) and inorganic phosphate (PO_4-P). Current velocity (cm sec^{-1}) was determined by means of an OTT meter, temperature (^{o}C) by means of a conventional mercury-in-glass thermometer, and pH by means of a portable field pH meter. Ammonia, nitrates and phosphates were determined by automatic analysis using a standard Technicon Auto-Analyser. Samples for these determinations were collected in clean microbiological universal bottles and two drops of concentrated hydrochloric acid were added to arrest biological activity. Analysis for total inorganic phosphate was carried out following the Technicon Industrial Method 3-68W. The methods recommended by Chapman et al. (1967) were employed for ammonia and nitrate determinations.

Hardness (mg l^{-1}) was determined by means of the BDH tests (BDH Chemicals Ltd., Poole, Dorset), involving the use of prepared reagents to determine total and calcium hardness, magnesium hardness then being determined by simple difference. All other determinations (mg l^{-1}) were performed as recommended by Department of the Environment (1972). Samples were collected in plastic screw-cap containers, except those intended for the determination of DO, which were collected in 250 ml glass bottles fitted with ground glass stoppers. These samples were 'fixed' in the field with previously prepared solutions of manganous sulphate and alkaline iodide.

Of the physico-chemical variables measured, only BOD deserves further explanation at this point. When organic matter is discharged to a watercourse, biochemical oxidation takes place as a result of the activity of micro-organisms, which utilise the organic matter as a source of carbon whilst consuming dissolved oxygen for respiratory purposes. The BOD test involves the incubation of water samples under standard conditions (in total darkness at 20 ^{o}C) for a given period of time (5 days). By determining the DO of the sample both before and after incubation, a value is obtained for the amount of oxygen consumed, and this is generally taken as an approximate measure of the amount of biochemically degradable organic matter in the sample.

4.3.2 Biological

4.3.2.1 Natural substrata

Natural substrata were sampled where possible simply by

removing the periphyton directly from submerged solid surfaces using a scraping implement, or by removing quantities of the actual substratum material together with the associated periphyton. Samples were placed directly into clean plastic screw-cap containers. Field notes were made at the time of collection to indicate the observed degree of development of the algal growths: where possible, an estimate of percentage cover was made by eye for macroscopically recognisable taxa such as Cladophora and Stigeoclonium, whilst in other cases, e.g. epilithic algal coatings, a note was made of whether these appeared to be poorly, moderately or well developed. An attempt was made to ensure that the samples taken were representative of the algal growths present at the station under consideration.

On return to the laboratory, samples were stored in a refrigerator and examined as soon as possible. The contents of each container were transferred to a shallow tray and examined macroscopically. Subsamples were then taken for microscopic examination. Any organisms encountered were identified as far as possible using the references cited in Section 3.1.3.1, and checking Whitton et al. (1978) for synonomy. Where possible, diatom preparations were made using the following method, based on Hasle and Fryxell (1970):

a) A relatively uncontaminated sample of diatom material was transferred to a clean universal bottle and allowed to stand until all the solid particles had settled. The supernatant water was then removed using a small pipette, leaving the sample (approximately 0.5 ml) in the bottom of the bottle.

b) An equal or slightly greater volume of concentrated sulphuric acid was added to and mixed with the sample, which was then allowed to stand for five minutes.

c) Approximately 1 ml saturated aqueous potassium permanganate was added and mixed, and again the sample was allowed to stand for five minutes.

d) Sufficient saturated aqueous oxalic acid was added to decolourize the solution, and the diatom material allowed to settle out.

e) The supernatant was discarded and the diatom material washed with distilled water and again allowed to settle out. This washing procedure was repeated until the supernatant was no longer acid, leaving a final volume of approximately 1 ml diatom suspension.

f) Drops of this suspension were dried on to cover glasses, and preparations were made using Styrax (G.B.I. Laboratories, Manchester), a mountant of high refractive index.

Work on any one sample ceased when it seemed that additional information was unlikely to result from the examination of further subsamples. Taking into consideration the field notes made at the time of sample collection, each taxon was assigned an abundance rating of 5 (abundant), 4 (common), 3 (frequent), 2 (occasional) or 1 (rare).

This semi-quantitative approach is of course open to criticism, especially on grounds of subjectivity, but it was considered to be justifiable for the purpose of routine sampling in the wide range of river types likely to be

encountered in any large scale surveillance exercise. Truly quantitative work, as explained in Section 3.1, would be extremely difficult and time-consuming, and if carried out less rigorously than strictly necessary, might actually present a spurious impression of accuracy. The approach adopted here was considered to be a reasonable compromise between truly quantitative work, and the presentation of simple species lists.

4.3.2.2 Artificial substrata

Three different types of artificial substratum were selected for investigation; these are illustrated in Figures 4.2 and 4.3 and described below.

(i) Red Quarry Tiles - heavy, unglazed tiles approximately 15 cm x 15 cm x 1.5 cm, the upper surface being uniformly flat but slightly rough to the touch. These were simply placed directly on to the natural substratum as desired, and were therefore only suitable for use in riffles.

(ii) Polythene Strips - strips of 500 gauge Polythene roughened on both sides with coarse sandpaper, were cut to a size of 30 cm x 5 cm. One end of each strip was folded over twice and the strips were secured in position by attaching them as shown either to metal tent pegs or to longer metal rods driven into the substratum in riffles and pools respectively. Figure 4.4 shows a polythene strip, still attached to a tent peg, recently removed from a riffle.

(iii) Perspex Plates - plates 0.5 cm in thickness were cut to a size of 13 cm x 5 cm and two holes, 0.4 cm diameter, were drilled through the end of each plate as shown. The plates were

FIGURE 4.2 (overleaf)
Artificial substrata - Red Quarry Tile, Perspex Plate, and Polythene Strip (all actual size)

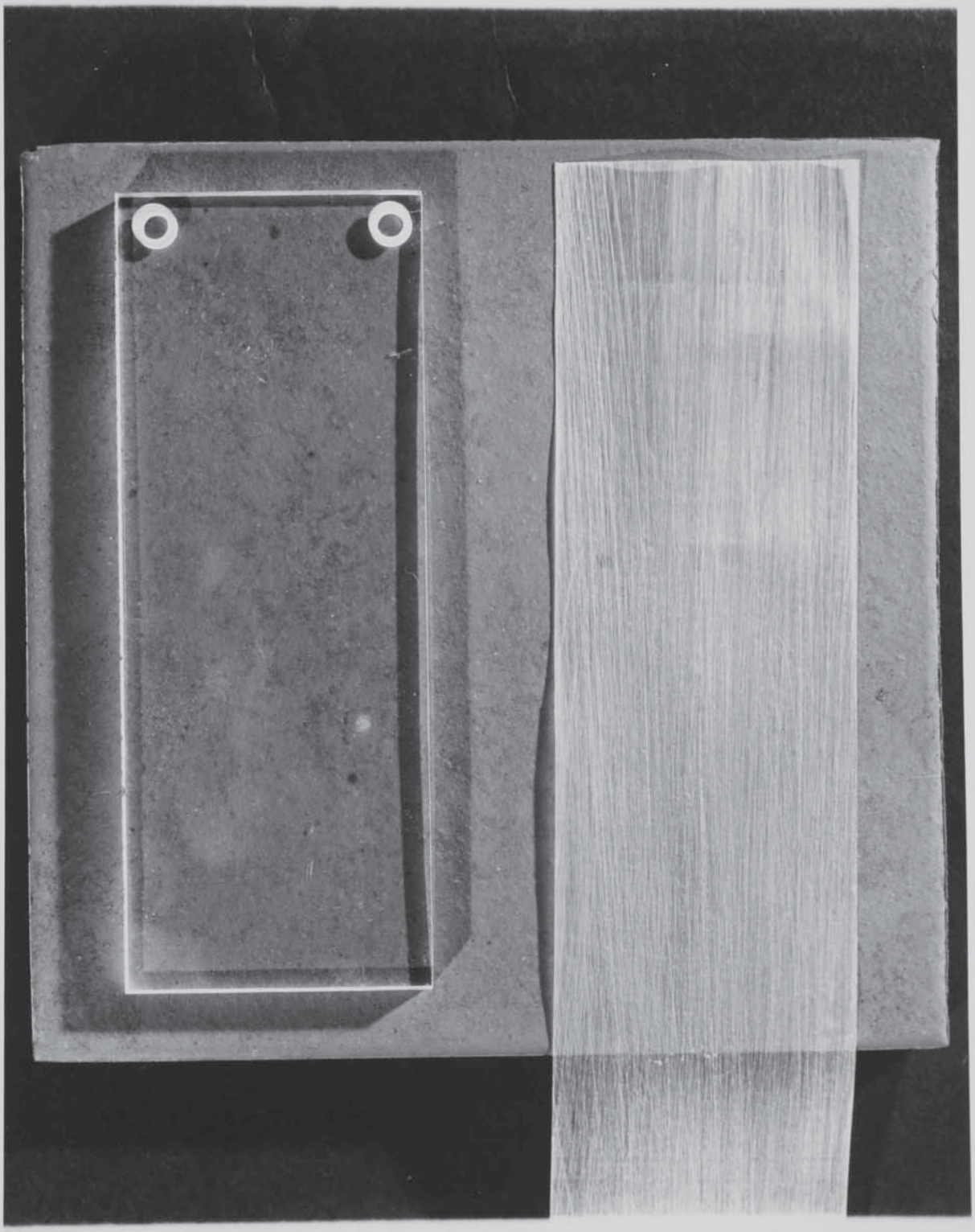


FIGURE 4.3 ANCHORAGE OF ARTIFICIAL SUBSTRATA

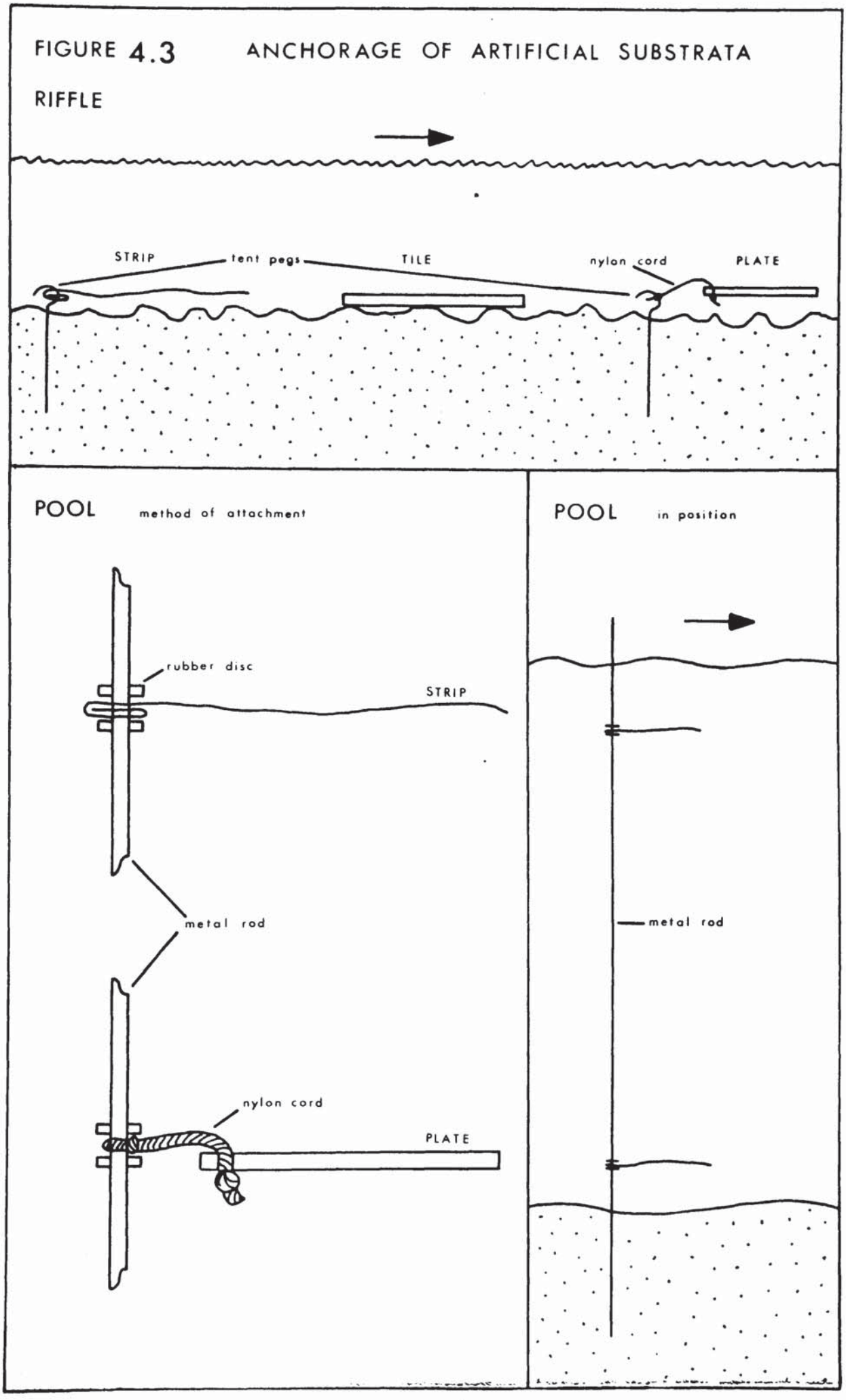


FIGURE 4.4 (overleaf)
Polythene Strip on removal from the riffle at Tean station 1, May 1976

again attached to tent pegs or metal rods by means of nylon cord threaded and knotted through the holes.

Strips and plates were anchored in position in the asbestos channels by means of short metal rods clamped vertically in position in such a way that their lower ends rested against the channel bottoms; these were arranged in pairs at intervals along the length of each channel.

Artificial substrata were left in position for the desired period of time.* Following recovery, they were carried back to the laboratory in suitable containers. Tiles and plates were most conveniently carried in plastic bags, but the strips were treated differently. A known length of strip (up to 20 cm) was cut off in the field, rolled up, and placed in a clean microbiological universal bottle.

On return to the laboratory, samples were again stored in a refrigerator and examined as soon as possible. For quantitative analysis, the periphyton was removed from a known area of artificial substratum, suspended in a known volume of water, and the suspension thoroughly and completely mixed. Removal was achieved by means of a toothbrush; periphyton was removed from the upper surface only of the tiles, but from equal areas of both the upper and lower surfaces of the strips and plates. The actual area cleaned, and the volume of water used for suspension depended on the degree of development of the periphyton. The dimensions of the artificial substrata were such that the calculation of a known area was rendered

* see page 130

relatively easy; in general, an area of at least 50 cm^2 was cleaned, and the periphyton suspended in 50-200 ml of water to produce a countable concentration of organisms. Counts were performed using a Sedgwick-Rafter cell (Woelkerling et al., 1976). For each sample, two microlitre squares from each of five separately filled cells were counted. Results were computed in terms of cell numbers per cm^2, but if cell counts were difficult, as in the case of filamentous forms, presence only was recorded. Separate samples were used for identification purposes, as described in the previous section, since only low power objectives can be used with this counting cell.

4.3.3 Structure of the Investigation

On 19th May 1976, artificial substrata were positioned in the river Tean and experimental channels as indicated below:

Station	Tiles	Strips	Plates
T1R	4	4	4
T1P	0	4*	4*
T2R	4	4	4
T2P	0	4*	4*
ERR	2	4	4
E50R	2	4	4
E75R	2	4	4
AR	2	2	2
A25	2	2	2
A50	2	2	2
A75	2	2	2
A100	2	2	2

*Two substrata were attached to each of two metal rods, as

shown in Figure 4.3, such that one substratum was within 30 cm of the water surface and the other within 30 cm of the bottom.

On 3rd June 1976, half the number of each type of substratum was removed from each station (at T1P and T2P, both the substrata attached to one of each pair of metal rods were recovered, i.e. one from near the surface and one from near the bottom). The immersion time for these artificial substrata was 15 days. The natural substrata (or channel walls, in the case of the asbestos channels) at each station were also sampled. The remaining artificial substrata were recovered on 16th June 1976 (total immersion time 28 days), and again the natural substratum at each station was sampled. Physico-chemical determinations were made at T1 and T2 at intervals of 2 weeks throughout the period of the investigation.

4.4 Results and Discussion

The physico-chemical data are presented in Appendix 1 (Table A1.5) and the biological data in Appendix 2 (Table A2.1), and these biological results are also summarized in Table 4.1 and Figure 4.5. Total numbers of taxa are reported for each type of substratum. For the artificial substrata, data are further reported as total numbers of diatom cells per cm^2. These diatom numbers were also used to calculate information theory diversity indexes: the formula used was that advocated by Wilhm and Dorris (1968) and discussed in Section 3.2.2.3. The calculations were executed by means of a Fortran program implemented at the University of Aston and run on the ICL 1904S computer situated there.

TABLE 4.1 Phase I: Summary of Data

IMMERSION		15d				28d			
SUBSTRATUM		N	T	P	S	N	T	P	S
TIR	No. Taxa	17	17	13	15	21	12	13	11
	No. cells cm^{-2}	-	90.0	11.7	23.5	-	18.8	31.8	27.3
	Diversity	-	1.86	2.99	2.94	-	2.64	2.64	2.59
	Similarity	-	0.71	0.67	0.63	-	0.61	0.65	0.63
	(p.135)								
TIP	No. Taxa	17		17 9	16 0	13		17 0	17 0
	No. cells cm^{-2}	-		29.2 3.5	10.1 0			28.7 0	25.2 0
	Diversity	-		3.15 2.70	3.26 0	-		3.14 0	3.30 0
	Similarity	-		0.65 0.46	0.73 -	-		0.67 -	0.67 -
T2R	No. Taxa	7	0	0	0	4	0	0	0
T2P	No. Taxa	4		0	0	1		0	0
AR	No. Taxa	18	14	0	17	6	9	0	11
	No. cells cm^{-2}	-	209.3	0	217.2	-	82.7	0	22.4
	Diversity	-	1.30	0	0.67	-	0.65	0	2.43
	Similarity	-	0.81	-	0.8	-	0.4	-	0.35
A25	No.Taxa	10	12	0	14	7	10	0	10
	No. cells cm^{-2}	-	39.6	0	231.3	-	4.8	0	10.2
	Diversity	-	1.66	0	0.48	-	2.86	0	2.61
	Similarity	-	0.82	-	0.75	-	0.59	-	0.59
A50	No.Taxa	15	16	0	0	10	10	0	0
	No. cells cm^{-2}	-	78.4	0	0	-	26.2	0	0
	Diversity	-	2.08	0	0	-	2.16	0	0
	Similarity	-	0.77	-	-	-	0.6	-	-
A75	No.Taxa	8	14	0	0	5	8	0	6
	No. cells cm^{-2}	-	27.2	0	0	-	25.4	0	13.2
	Diversity	-	2.19	0	0	-	2.18	0	1.58
	Similarity	-	0.73	-	-	-	0.46	-	0.36
A100	No.Taxa	5	4	0	0	2	3	4	4
	No. cells cm^{-2}	-	100.4	0	0	-	148.0	14.5	4.7
	Diversity	-	1.21	0	0	-	0.87	0.61	1.10
	Similarity	-	0.44	-	-	-	0.8	0.67	0.67
ER	No. Taxa	14	9	0	0	4	0	0	0
	No. cells cm^{-2}	-	3.3	0	0	-	0	0	0
	Diversity	-	1.90	0	0	-	0	0	0
	Similarity	-	0.7	-	-	-	-	-	-
E50	No.Taxa	7	0	0	0	1	0	0	0
E75	No.Taxa	8	0	0	0	1	0	0	0

N = Natural substrata; T = Tile; P = Perspex Plate; S = Polythene Strip.

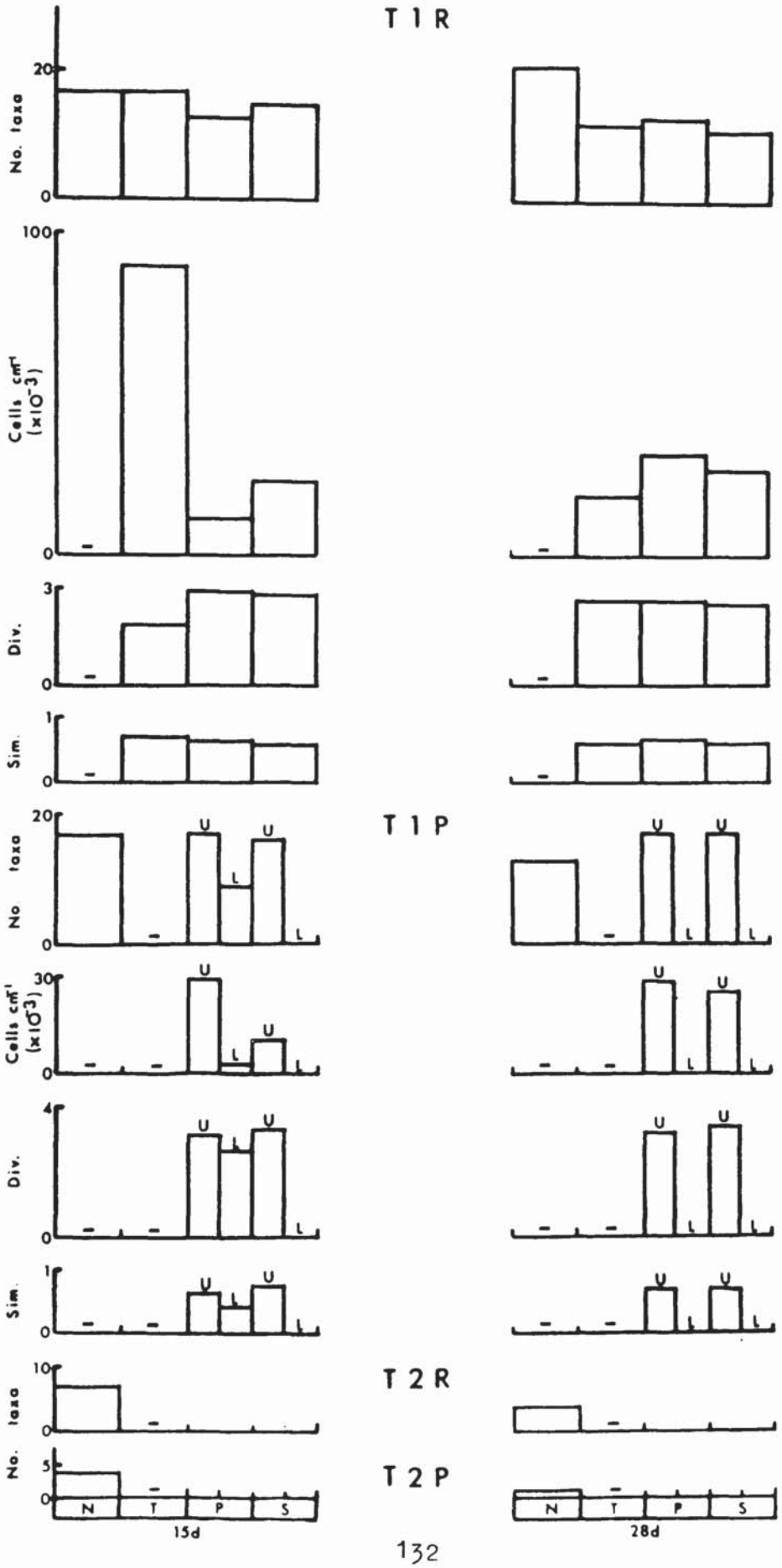
No. cells cm^{-2} ($\times 10^{-3}$) and Diversity Index calculated from diatom data only.

TIP: Two figures refer to upper and lower artificial substrata.

FIGURE 4.5 Phase 1: Periphyton Data

N = Natural substrata
P = Perspex Plates
T = Tiles
S = Polythene Strips

U = Upper)
L = Lower) Artificial Substrata



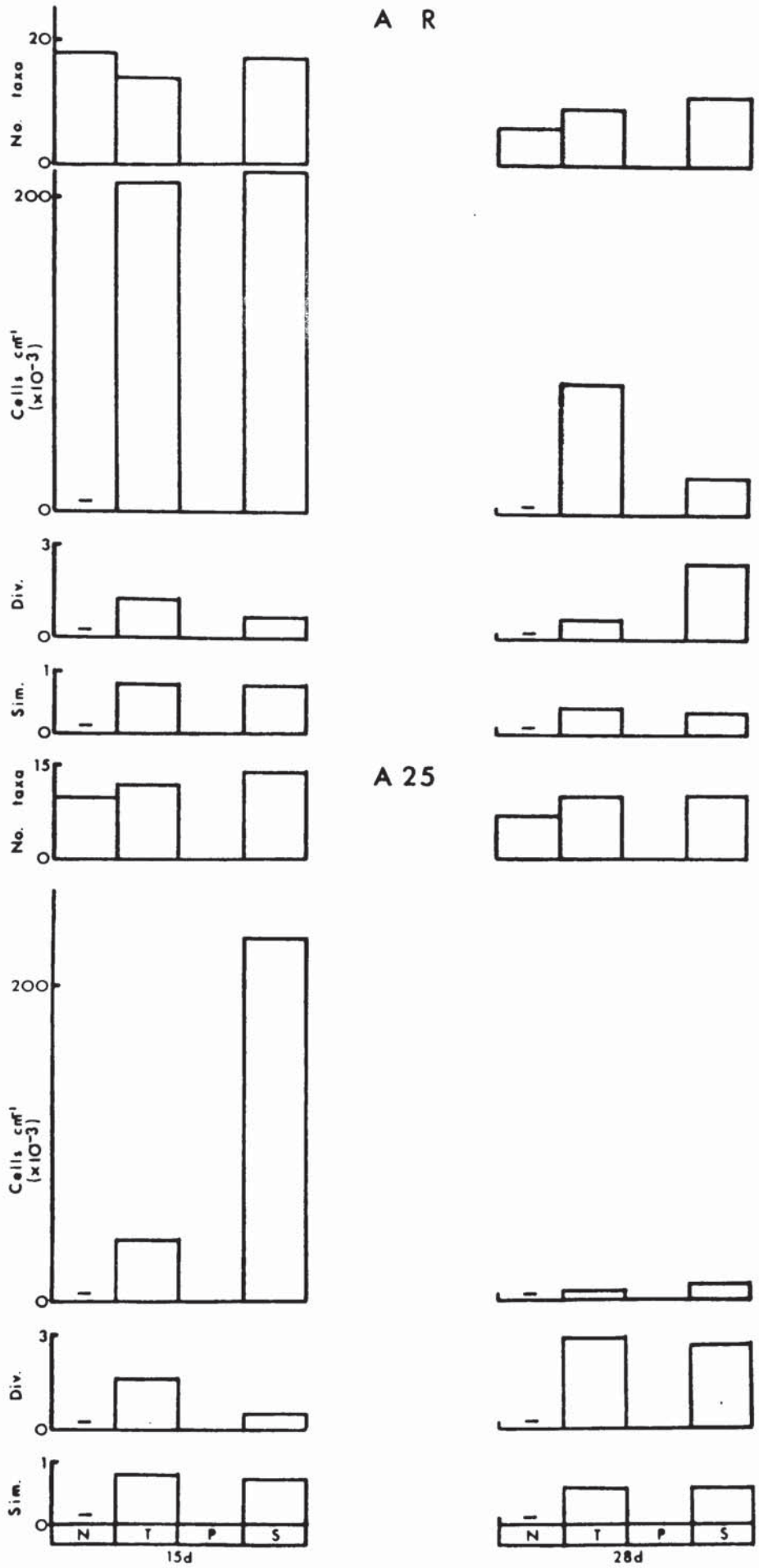
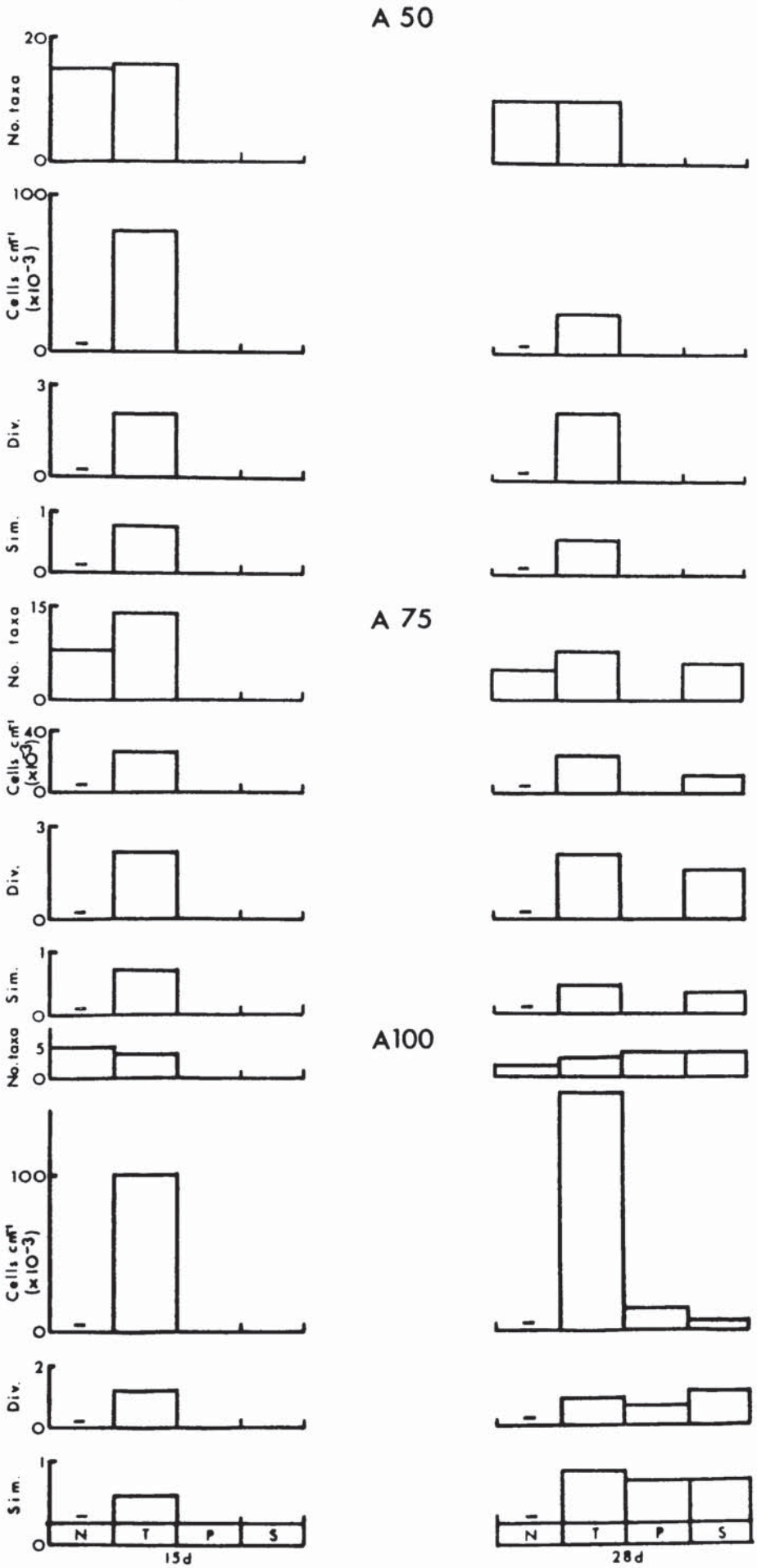

A R
No. taxa
20
0
Cells cm³ (×10⁻³)
200
0
Div.
3
0
Sim.
1
0
A 25
No. taxa
15
0
Cells cm³ (×10⁻³)
200
0
Div.
3
0
Sim.
1
0
N
T
P
S
15d
28d

FIGURE 4.5 continued



In addition, the species lists derived from the artificial substrata were compared with those derived from the corresponding natural substrata using the Sorensen (1948) similarity coefficient, I:

$$I = 2c / (a + b)$$

where a = the number of species in community A (natural substratum),

b = the number of species in community B (artificial substratum), and

c = the number of species common to both A and B.

After 15 days immersion at T1R, the tiles supported as many taxa as the natural substratum, but fewer taxa were encountered on the plates and the strips. After 28 days, the natural substratum was richer in taxa but the artificial substrata supported fewer taxa than at 15 days, with the exception of the plates which supported the same number as before. After 15 days, the tiles supported a large total diatom standing crop, but diversity was comparatively low. After 28 days, however, diatom standing crop on the tiles had fallen markedly, whilst the plates and strips supported higher standing crops than before. Diversity indexes were comparable for all substrata at the 28 day period. Similarity coefficients were also comparable for all substrata at both sampling intervals. At T1P it is noticeable that only those plates and strips placed near the water surface were effective, yielding as many taxa as the natural substratum after 15 days, and more than the natural substratum after 28 days. Diatom standing crops were lower than in the riffle, but diversity indexes were higher and similarity coefficients comparable. At both T2R and T2P, numbers of taxa on the natural substrata were

lower than the corresponding upstream stations, and all the artificial substrata failed to support periphytic growth, owing to the accumulation of large quantities of drifting Cladophora and debris.

The results obtained from the asbestos channels are rather fragmentary as only the tiles consistently yielded useful information. This was again because the plates and strips tended to accumulate unwanted material; generally, however, the strips performed more effectively than the plates, probably because their own flexibility discouraged excessive fouling. In general, longer immersion in the asbestos channels tended to result in lower numbers of taxa, lower standing crops and lower similarity coefficients on all artificial substrata, but diversity was frequently higher or at least similar after 28 days. The results from the earth channels were poor, with all artificial surfaces except tiles failing to yield useful data.

The results of this Phase 1 work together with the experience gained whilst carrying it out enable the following general points to be made:

(i) Natural substrata are difficult to sample quantitatively, but relatively easy to sample qualitatively with an essentially subjective estimation of the relative importance of the taxa present. In general, riffles would be expected to be more readily sampled in this way than would pools.

(ii) Artificial substrata may overcome some of the difficulties associated with the direct quantitative sampling of natural substrata, particularly in pools, but the use of

artificial substrata is likely to create additional problems which must be considered. Ecologically, the species lists derived from artificial substrata are unlikely to be exactly the same as those derived from the corresponding natural substrata, and the relative quantitative importance of taxa on the different substrata is also likely to differ. On a more practical level, artificial substrata may prove difficult to anchor satisfactorily in position, and in some situations, colonization may be discouraged or prevented by the accumulation of unwanted material.

(iii) Should it be decided to use artificial substrata, one of the most important considerations is practicality. The ideal artificial substratum for routine work would possess the following characteristics:

a) Readily re-useable, or inexpensive and disposable

b) Simple - easy to construct and anchor in position, and convenient to handle.

c) Virtually indestructible

d) Unlikely to accumulate excessive quantities of unwanted material (sediment, detritus, larger plant material and debris)

e) Inconspicuous in position, yet easily located and recovered.

In the Phase I investigations, Polythene strips proved to be far superior in terms of practicality to the other artificial substrata. They are the least expensive and are disposable - the others must be cleaned very thoroughly before re-use. A known length of Polythene strip may be cut off in the field, rolled up and placed in a universal bottle for transportation.

In the laboratory, the Polythene roll of known area may be withdrawn and cleaned, and the bottle washed out to recover any detached material. The other substrata were less convenient to handle, and the inevitable detachment of material during transportation must have introduced error into the subsequent quantitative work.

When in position in the river, the flexible Polythene strips undulated gently in the current and offered little resistance to passing large objects, thus minimizing the accumulation of unwanted material. The Perspex plates tended to accumulate more debris, and the tiles tended to accumulate more finely divided material which interfered with subsequent counting.

It was on these essentially practical grounds that Polythene strips were selected for sampling the deeper reaches of a wider range of rivers in Phase 2, (Section 5).

5. THE RIVER SURVEYS (PHASE 2)

5.1 Objectives

The objectives of Phase 2 (see Section 2.1) were to evaluate the performance of the Polythene strip samplers selected in Phase 1 of the investigation in the deeper reaches of a wider range of river types and water qualities, particularly where direct sampling of the natural substrata might be difficult or unproductive, and further to assess the suitability of the data so generated for the biological surveillance of river water quality.

5.2 The Sampling Stations

With the co-operation of the appropriate Water Authorities, the rivers and sampling stations listed in Table 5.1 were selected for study. Where available, nearby riffles were also studied, in order to establish any relationships between the assemblages growing on the strips and those growing in a riffle under similar water quality conditions. One river, the Churnet, was chosen for special investigation: 14 riffle stations were selected at points along the course of this river, but at only 2 of the sites were associated pools also sampled using the Polythene strips.

Figure 5.1 indicates the broad geographical distribution of the rivers involved in the survey, whilst more detailed maps of the Weaver, the Trent system, and the Churnet are presented at appropriate points throughout the Results and Discussion section. Figure 5.2 illustrates the range of river types sampled in the

TABLE 5.1 Phase 2 Sampling Stations

Water Authority	Sampling Station	Location	National Grid ref.	Riffle/ Pool	
North-West	Weaver 1	Hankelow Mill	SJ658450	R	P
	Weaver 2	Windy Arbour	SJ657544		P
	Weaver 3	Church Minshull	SJ667608	R	P
	Weaver 4	Weaver Hall	SJ670644		P
Anglian	Nene 1	Whiston	SP845618	R	P
	Nene 2	Stanwick	SP967712	R	P
	Nene 3	Wansford	TL084997		P
	Nene 3	Water Newton	TL104977	R	
Yorkshire	Foss	Strensall	SE625605	R	P
	Don	Conisbrough	SK509995		P
Wessex	Avon	Twerton	ST726648		P
	South Drain	Huntspill	ST367430		P
Welsh	Wye 1	Hereford	SO532390		P
	Wye 2	Ross	SO592256		P
Severn-Trent	Severn 1	Bewdley	SO788754	R	P
	Severn 2	Mythe	SO889336		P
	Trent 1	King's Bromley	SK126176	R	P
	Trent 2	Walton	SK213182		P
	Trent 2	Catton Hall	SK205155	R	
	Trent 3	Gunthorpe	SK682437		P
	Trent 4	Kelham	SK776557	R	P
	Tame 1	Water Orton	SP175915		P
	Tame 1	Castle Bromwich	SP137903	R	
	Tame 2	Elford	SK190103	R	P
	Derwent 1	Allestree	SK358398	R	P
	Derwent 2	Draycott	SK444327		P
	Tean 1	Checkley	SK028376	R	P
	Tean 2	Beamhurst	SK059361	R	P
	Mease	Croxall	SK192140	R	P
	Churnet T	Tributary	SK013607	R	
	Churnet 1	Upper Hulme	SK012606	R	
	Churnet 2	Middle Hulme	SK993606	R	
	Churnet 3	below Reservoir	SJ993581	R	
	Churnet 4	Abbey Green Rd.	SJ978572	R	
	Churnet 5	Bridgend	SJ972572	R	
	Churnet 6	Cheddleton	SJ973526	R	P
	Churnet 7	Basford Br.	SJ982521	R	
	Churnet 8	Froghall	SK026468	R	
	Churnet 9	Oakamoor	SK053443	R	
	Churnet 10	Alton	SK072426	R	P
	Churnet 11	Denstone	SK101412	R	
	Churnet 12	Rocester	SK104391	R	
	Churnet 13	Churnet Mouth	SK101376	R	

FIGURE 5.1 MAP OF ENGLAND AND WALES TO SHOW THE RIVERS STUDIED

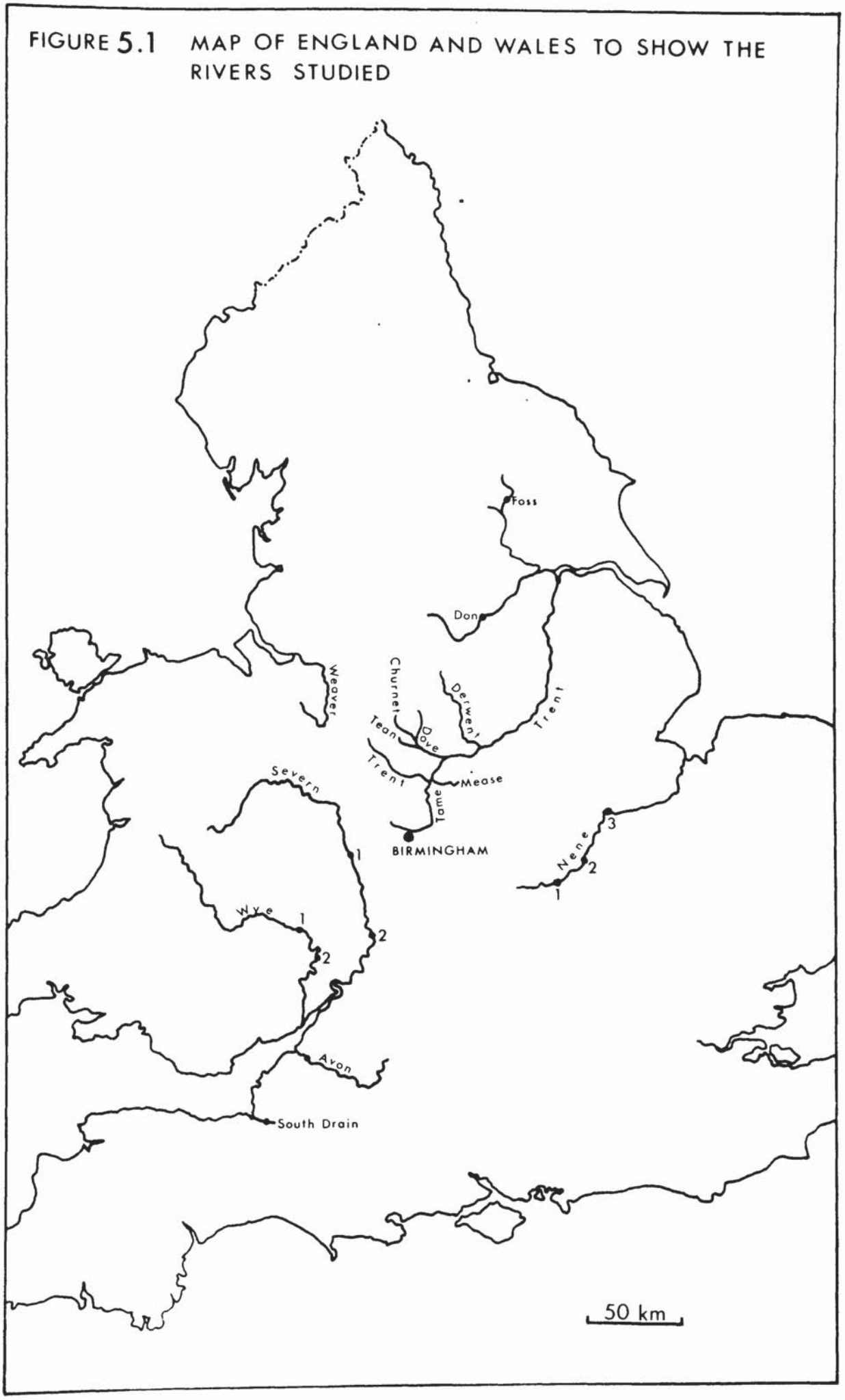


FIGURE 5.2 (overleaf)
Examples of sampling stations used in the survey, illustrating different river types

FIGURE EXAMPLES OF SAMPLING STATIONS USED IN THE SURVEY ILLUSTRATING DIFFERENT RIVER TYPES

A. Tributary stream of River Churnet — Head stream

B. River Meese Riffle — Rhithron

C. River Weaver Station 1 Pool — Rhithron

D. River Nene Station 2 — Lowland river

E. South Drain, Wessex — Drainage dyke

F. River Severn, The Mythe — Potamon

survey. Further information on the physico-chemical characteristics of the different sites, and on polluting discharges and water quality, is again presented as appropriate throughout Section 5.4.

5.3 Materials and Methods

These were essentially the same as described in Section 4.3. At each pool site, three Polythene strips were positioned, each on a separate metal rod, near to the bank but in the main river flow, and within 1 m of the water surface. On each sampling visit, the strips positioned on the previous visit, if any, were recovered and replaced by a new set, and if possible, the natural substrata were sampled at the pool site itself, or at the associated riffle, or both. Biological samples were treated in the same way as described in Section 4.3. The same physico-chemical determinations were also carried out, and the resulting data were in many instances supplemented by further physico-chemical data supplied by the Water Authorities themselves.

The Phase 2 investigations were planned to occupy the whole of the calendar year 1977, although the Churnet survey was extended further, into May 1978. Most of the stations were visited at intervals of 4 weeks, but those rivers situated a considerable distance from Birmingham - the Foss, Don, Nene, Avon and South Drain - were visited at alternating intervals of 4 and 8 weeks. The precise sampling dates are given in the Appendixes.

5.4 Results and Discussion

The physico-chemical data are presented in Appendix 1 (Tables

A1.1 to A1.12) and the biological data in Appendix 2 (Tables A2.2 to A2.15).

Work on most rivers was delayed until March 1977, owing to periods of very heavy rain and high water levels during the early part of the year. Sampling commenced at most stations when flow conditions were still erratic, but continued virtually uninterrupted throughout the year, until December. The results were, however, very fragmentary, with many sites and many strips failing to yield satisfactory data. For this reason, the results from each river are now considered only briefly, with a further discussion of the Polythene strip data in Section 5.4.6.

5.4.1 The Weaver

Of all the rivers in which Polythene strips were used extensively, the Weaver (Figure 5.3) furnished perhaps the most satisfactory and complete data. Although some small sewage discharges occurred above stations 1 and 2, the major discharge was that from the Crewe area, which entered between stations 2 and 3. The chemical data are summarized in Table 5.2, indicating the deterioration in water quality at station 3. Of the four stations chosen for investigation, riffles were present only at stations 1 and 3. The riffle substratum at station 1 was physically unstable, consisting predominantly of small stones and sand. In this respect, there was comparatively little differentiation at station 1 between the riffle and the pool, which was shallow (1-2 m) with an unstable sandy and muddy substratum. The riffle substratum at station 3 was in contrast physically very stable, with a preponderance of large stones and rocks. The pool

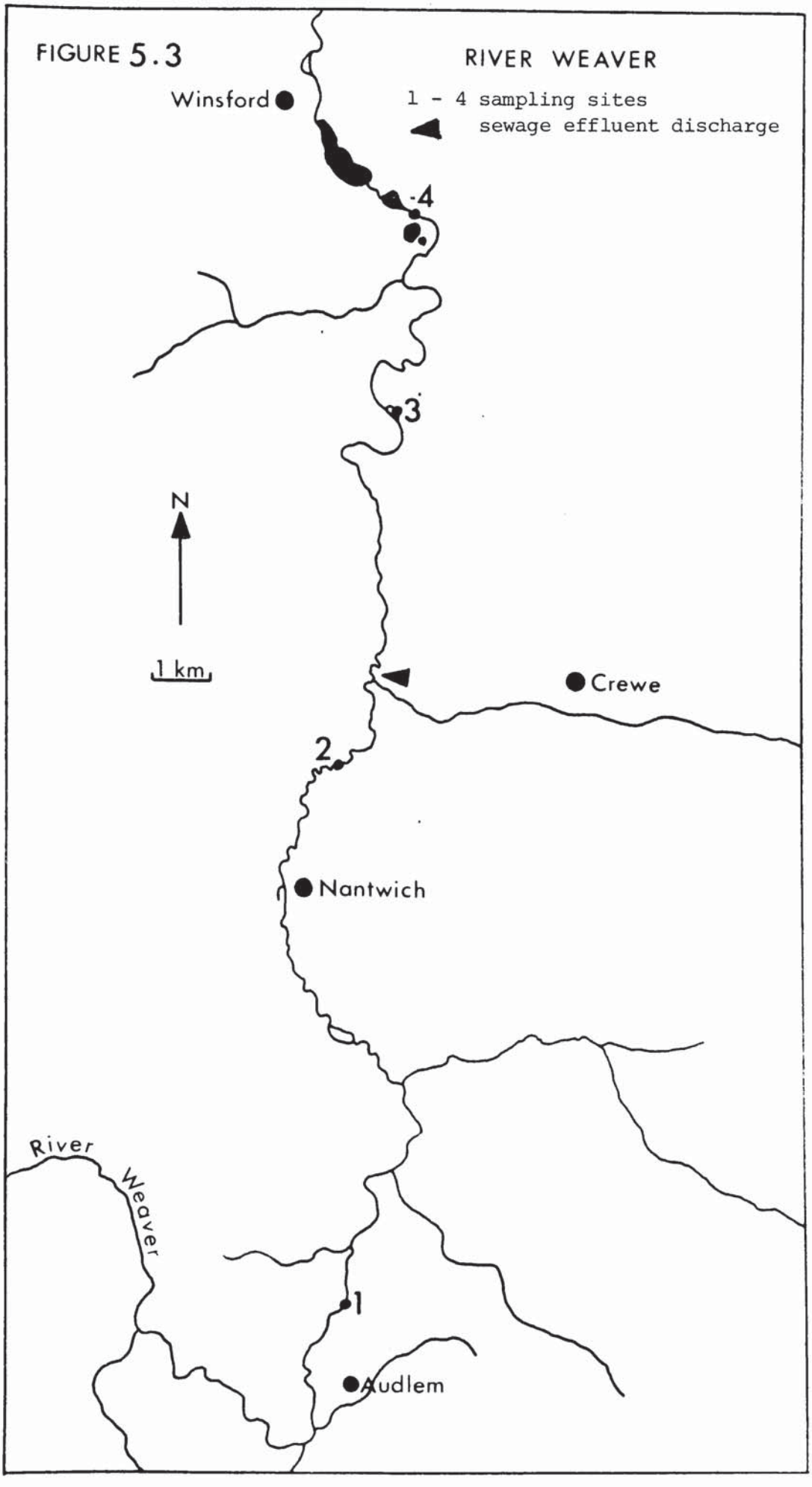


FIGURE 5.3
RIVER WEAVER
Winsford
1 - 4 sampling sites
sewage effluent discharge
4
3
N
1 km
Crewe
2
Nantwich
River
Weaver
1
Audlem

TABLE 5.2 River Weaver 1977 Chemical Data (mg l^{-1}) Means and Ranges

Stn.	Data	SS	DO	BOD	NH_3	NO_3
1	Aston	5.0 (0-9.0)	8.3 (6.1-11.2)	- -	1.4 (0.5-3.2)	6.7 (5.2-9.1)
	WA	14.0 (5.0-38.0)	9.6 (7.5-12.0)	3.8 (1.9-6.5)	0.6 (0.1-2.1)	7.4 (4.5-14.0)
2	Aston	16.0 (2.0-79.0)	10.2 (8.0-13.0)	- -	1.3 (0.8-2.3)	9.2 (6.5-14.4)
	WA	19.0 (3.0-61.0)	10.2 (8.3-12.3)	4.9 (2.3-12.0)	0.7 (0.1-2.7)	8.7 (6.5-14.5)
3	Aston	11.0 (5.0-27.0)	7.2 (4.9-10.3)	- -	3.7 (1.9-6.7)	7.5 (5.4-12.2)
	WA	21.0 (2.0-103.0)	7.8 (4.1-11.2)	7.7 (2.9-24.0)	2.7 (1.1-4.8)	7.6 (5.4-15.0)
4	Aston	9.0 (3.0-18.0)	6.3 (3.2-10.2)	- -	3.2 (1.8-4.9)	8.1 (6.0-11.8)

W.A. = Water Authority

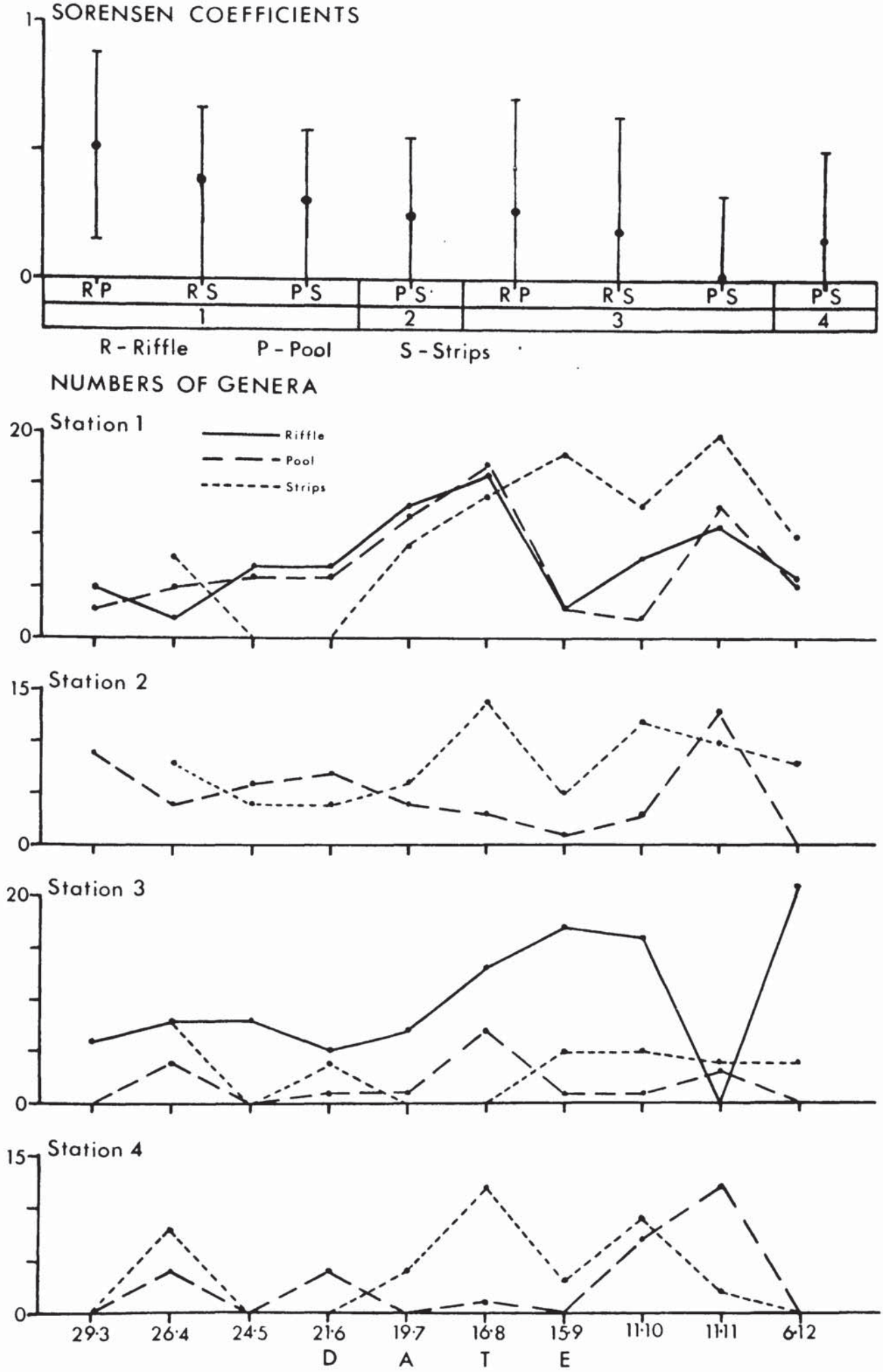
here was virtually inaccessible, however, and it was possible only to sample the firm mud close to the bank, where the Polythene strips were positioned. The pools at stations 2 and 4 were different in character again, with fine sand and mud at station 2, and mud and silt at the wider and deeper station 4.

On only one occasion was it not possible to take a sample from the natural substratum at any one site - the riffle at station 3 was inaccessible owing to high flows on 11th November. The Polythene strips were recovered intact on all occasions, but on 24th May a fall in flow left them stranded above water level at stations 1, 3 and 4.

The different substrata are compared in terms of Sorensen's similarity coefficients (Section 4.4) in Figure 5.4. At stations 1 and 3, comparisons can be made between the riffle and the pool, the riffle and the strips, and the pool and the strips (RP, RS and PS respectively). At stations 2 and 4, however, the only comparisons possible are of course between the pool and the strips (PS). The coefficients are plotted as means (with ranges) for the entire survey. It should be noted that similarity values of zero are recorded in the event of both samples having no common species, or no species at all.

The highest similarity values are obtained when comparing the riffle with the pool at station 1, this reflecting the physical similarity between the two sites. The RS and PS values are lower but approximately equivalent, as might be expected. The remaining Sorensen values for all pairs of samples at all

FIGURE 5.4 River Weaver: Biological Data



stations are comparatively low, indicating low similarity between the different natural and the artificial substrata. This is particularly noticeable at station 3, where similarity between the pool and the strips is very low.

Further information is obtained by considering the temporal variation in numbers of taxa recorded from each substratum type at each of the four stations (also shown in Figure 5.4). Comparing stations 1 and 3, it can be seen that both riffles are capable of supporting a rich epilithic flora. At station 1, the numbers of genera in the pool were always comparable to those in the riffle, but this was not the case at station 3, where the pool was always poor in genera. Further, the Polythene strips at station 1 performed well, supporting larger numbers of genera than either the riffle or the pool towards the end of the year, whilst the strips at station 3 performed less satisfactorily. The differences in similarity coefficients between the two stations discussed above would further indicate that different ecological factors were operating at each one. Water quality deterioration at station 3 was not reflected by the numbers of genera found in the riffle on account of its physical stability. It appears however that water quality deterioration is reflected by the lower numbers of genera on the strips at this station, but this argument is in fact specious; colonization of the strips at station 3 was most probably reduced by the accumulation of large quantities of entrapped Cladophora, which was particularly abundant in July and August. The presence of this alga alone was a more reliable indication of water quality deterioration below Crewe.

At stations 2 and 3, the strips performed relatively effectively, often yielding larger numbers of genera than the natural pool substrata.

The Weaver survey suggested above all that data can only be interpreted with a knowledge of the physical characteristics of a river, and that even the physical differences between supposedly comparable riffles may influence data interpretation. For this reason also it may be difficult to compare different rivers, even if they appear to be similar in many respects.

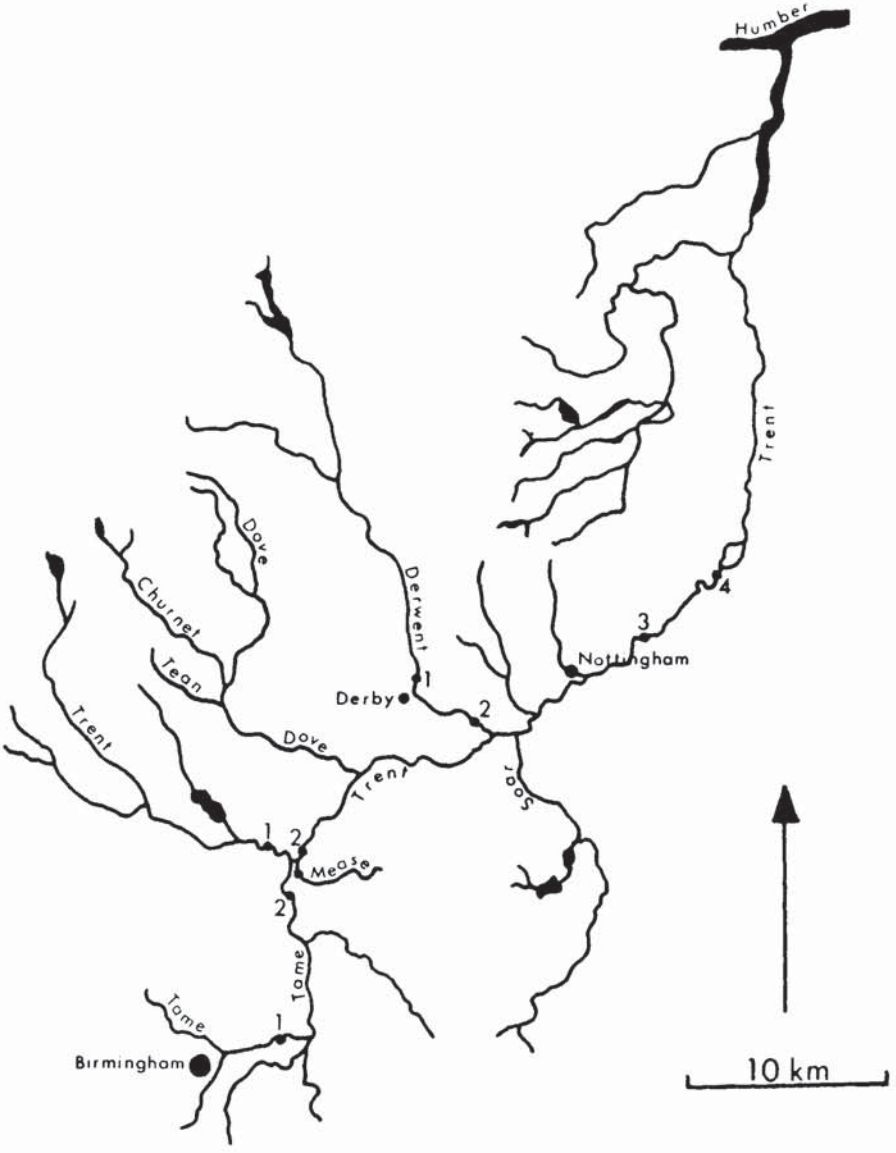
5.4.2 The Trent System

Water quality in the Trent System (Figure 5.5) has been discussed in some detail by Lester (1975). The Trent rises 11 km to the north of Stoke, and flows in a southerly direction through that city, meeting the Tame at Wychnor, a further distance of 68 km. The river then flows in a north-easterly direction through Burton, after which it is joined by the Dove and the Derwent from the north, and the Soar from the south. Continuing on through Nottingham and Newark, the Trent passes through more open country to the Humber estuary, its total length being 274 km.

The Trent system is unusual in that the majority of the human population live on the headwaters of the river or one of its tributaries. Although the Trent receives a considerable volume of domestic and industrial effluent from Stoke and the Potteries (population 400,000), the major source of pollution is the River Tame, which rises in the Wolverhampton area, and with its

FIGURE 5.5 THE TRENT SYSTEM

Sampling stations on each river are numbered.



tributaries drains most of the West Midlands, including Birmingham and the Black Country, representing a total population of over 2.5 million. The Dove and the Derwent are the only major tributaries of the Trent remaining relatively unpolluted, although the Churnet (Section 5.4.3), a tributary of the Dove, receives a substantial proportion of domestic and industrial effluent, and the Lower Derwent receives sewage effluent from the city of Derby, with a population of 200,000. The city of Leicester and its environs (population 400,000) discharge their wastes to the headwaters of the Soar, the other major southern tributary of the Trent.

In this section it is convenient to consider the results obtained from the rivers Tame, Trent, Mease, Derwent and Tean (Appendix Tables A2.3 to A2.7), the Churnet being considered separately in the next section. The chemical data are summarized in Table 5.3. The use of artificial substrata in these rivers proved to be very disappointing with many strips failing to yield results owing to factors such as fouling and scouring as well as simple loss or inaccessibility. The results obtained from the natural substrata, particularly the riffle sites (where present) were generally of greater value. The most productive sampling times tended to be in the early part of the survey (i.e. spring and early summer), and in the autumn months, and the most important water quality indicators were the filamentous green algae Stigeoclonium and Cladophora.

In the river Tame, most of the Polythene strips failed at both stations throughout the survey owing mainly to fouling by

TABLE 5.3 Trent System 1977 Chemical Data (mg l^{-1}) Means and Ranges

R. Trent

Stⁿ.	Data	SS	DO	BOD	NH_3	NO_3
1	Aston	13.8 (1.0-27.0)	9.9 (8.9-11.2)	- -	1.7 (0.7-5.1)	8.5 (6.7-10.6)
	WA	25.0 (1.8-84.0)	10.3 (7.3-15.1)	4.3 (1.8-9.6)	0.3 (0.1-0.8)	9.4 (7.0-12.0)
2	Aston	21.6 (10.0-52.0)	7.2 (6.2-9.1)	- -	2.9 (1.0-7.0)	14.1 (10.2-26.8)
	WA	33.0 (10.0-256.0)	7.6 (4.3-10.2)	10.2 (4.0-17.2)	1.3 (0.3-2.6)	12.5 (10.0-19.2)
3	WA	26.0 (8.0-74.0)	9.1 (7.5-10.6)	6.4 (3.8-15.8)	0.7 (0.3-1.5)	9.4 (6.8-12.0)
4	WA	29.0 (8.0-178.0)	9.1 (7.1-11.5)	6.2 (2.5-9.8)	0.5 (0.1-1.1)	10.1 (7.5-15.7)

R. Tame

Stⁿ.	Data	SS	DO	BOD	NH_3	NO_3
1	Aston	24.6 (16.0-35.0)	7.2 (6.5-8.4)	- -	5.8 (1.8-8.9)	10.7 (7.8-13.6)
	WA	42.0 (13.0-256.0)	7.6 (3.3-9.6)	12.1 (5.5-33.0)	5.5 (1.6-10.0)	7.6 (0.2-11.0)
2	Aston	23.5 (10.0-46.0)	6.8 (5.2-8.8)	- -	3.7 (1.7-7.5)	14.4 (5.1-25.6)
	WA	21.0 (21.0)	8.9 (8.9)	10.5 (10.5)	3.7 (3.7)	0.7 (0.7)

R. Mease

	Data	SS	DO	BOD	NH_3	NO_3
	Aston	14.2 (5.0-38.0)	10.4 (8.0-13.2)	- -	1.9 (0.85-6.5)	8.9 (4.8-13.9)
	WA	30.0 (1.0-382.0)	10.3 (5.9-6.3)	2.4 (0.5-6.3)	0.2 (0.1-0.6)	10.3 (5.2-20.8)

CONTINUED

W.A. = Water Authority

TABLE 5.3 continued

R. Derwent

St^{n}.	Data	SS	DO	BOD	NH_3	NO_3
1	WA	16.0 (6.0-46.0)	10.8 (9.0-13.0)	2.4 (1.5-4.4)	0.2 (0.1-0.3)	4.1 (3.0-6.4)
2	WA	13.0 (7.0-31.0)	8.8 (5.1-11.4)	3.9 (0.6-7.5)	0.4 (0.1-0.8)	4.8 (3.2-7.1)

R. Tean

St^{n}.	Data	SS	DO	BOD	NH_3	NO_3
1	Aston	16.4 (2.0-102.0)	10.0 (5.9-13.3)	3.1 (0.5-8.8)	1.4 (0.5-3.05)	4.4 (1.7-6.0)
	WA	19.0 (4.0-61.0)	10.7 (8.5-11.8)	2.8 (1.4-6.0)	0.3 (0.1-0.7)	4.5 (3.4-5.7)
2	Aston	13.8 (7.0-33.0)	7.3 (3.7-11.1)	7.9 (4.0-14.0)	1.5 (0.5-3.0)	8.0 (2.9-11.6)
	WA	35.0 (4.0-427.0)	9.7 (7.5-11.1)	5.1 (2.2-12.0)	0.5 (0.1-1.8)	8.8 (4.7-12.6)

WA = Water Authority

detached filamentous algae and other plant material and debris. The growth and abundance of Stigeoclonium and Cladophora at the riffle sites was however indicative of water quality, with well-developed growths of Stigeoclonium at station 1 and Cladophora at station 2 reflecting the trend from organic pollution to inorganic enrichment.

The occurrence of these taxa in the Trent itself was also very informative, with Cladophora well-developed at station 1, but less so at station 2, where the additional presence of Stigeoclonium indicated the deterioration in water quality associated with the entry of the Tame. Stigeoclonium was not found further downstream at Trent stations 3 and 4, although Cladophora persisted in small stands, probably only where substratum and flow conditions were suitable.

The results obtained from both natural and artificial substrata in the river Mease were very disappointing considering the relatively good quality of the water. The riffle supported well-developed growths of Cladophora and Enteromorpha as well as the macrophyte Ranunculus fluitans, but these blanketing growths probably discouraged the development of an extensive epilithic microflora. The Polythene strips positioned on 30th May were lost, and since it was suspected that they had been removed deliberately, were not replaced until 22nd August. Those strips that were recovered successfully tended to be fouled by plant debris, however, and therefore yielded few results.

In the river Derwent, the strips again performed poorly, and

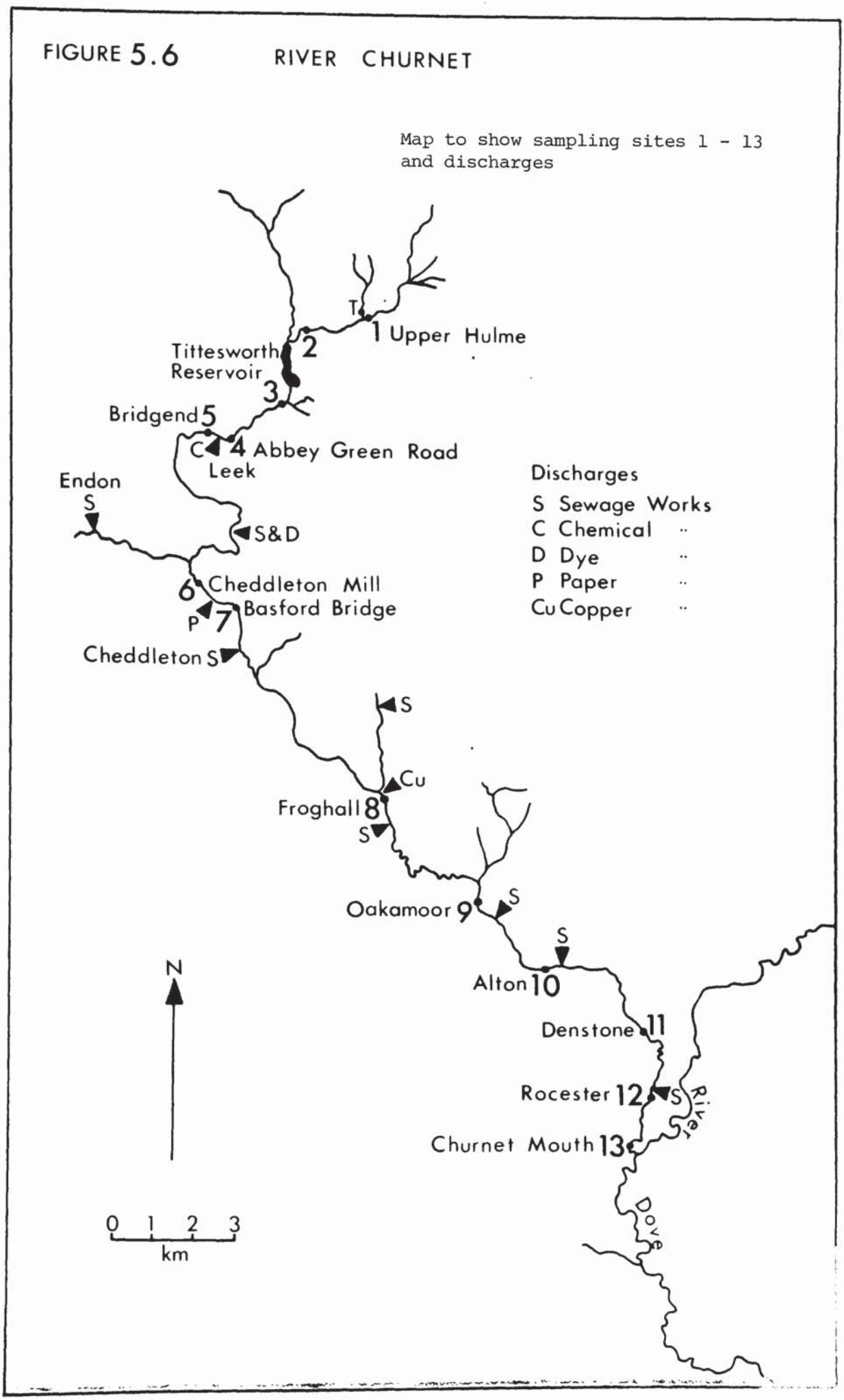
the differences between the natural substrata at the two stations were probably a result of physical, rather than water quality, differences. The riffles at station 1 supported a reasonably well-developed diatom community with additional growths of Cladophora. There was no riffle at station 2, below the Derby effluent, but the pool site had a stony littoral region apparently capable of supporting an epilithic flora similar in character to that of the station 1 riffle, but not always accessible or well-developed, owing to erratic flow conditions.

The river Tean was notable for the massive development of Cladophora on the natural substrata at station 2 below the sewage works discharge, thus tending to foul the strips and prevent colonization. As in the Weaver survey, the mere presence of this alga was probably the most useful indication of water quality deterioration at the downstream station.

5.4.3 The Churnet

The river Churnet (Figure 5.6) flows south and south-east around the south-western edge of the Derbyshire Peak District, and joins the river Dove near Rocester, about 41 km downstream of Tittesworth reservoir. In this distance, the river falls about 92 m, an average of 2.25 m km^{-1} although the gradient is much steeper immediately below the reservoir (16 m km^{-1}) and also upstream of Froghall (38.5 m km^{-1}) where the river appears to cross a fault in the Coal Measures. The greater part of the land in the watershed is agricultural, although the steep sides of the Churnet valley are wooded. Most of the human population lives in and around Leek, in the upper quarter of the river's length.

FIGURE 5.6 RIVER CHURNET

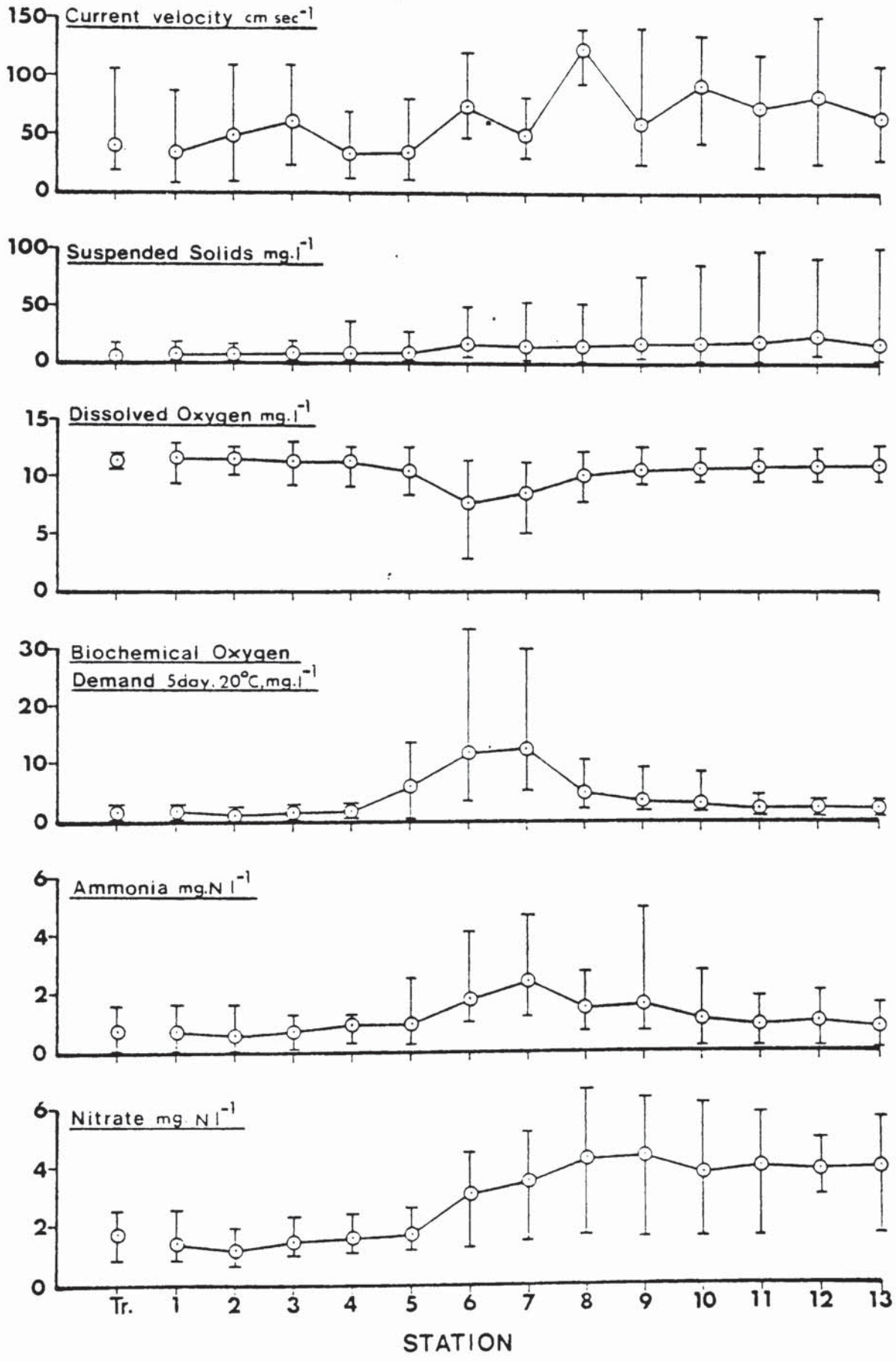


Here are sited a chemicals factory and a number of textile dye works. A paper mill is situated further downstream at Basford, and a copper works at Froghall. Sand is quarried and refined near Oakamoor for glass manufacture, and at Rocester agricultural and earth-moving machinery is made. Eight sewage works in the area treat a total of about 3.5 mgd, the major part of this (3 mgd) being from Leek.

The river was the subject of an early series of studies by Pentelow and Butcher (1938) and Butcher (1946, 1955); these were mentioned in Section 3.2.1.3 in relation to metal pollution (from the Froghall works). Later investigations by Solbé and Cooper (1975) were concerned primarily with the fish populations.

In the present investigation, fourteen riffle stations were sampled semi-quantitatively each month over a period of fourteen months. One station, "T", was located in a small tributary stream at Upper Hulme, the remaining thirteen stations being situated on the river itself. Current velocity and selected chemical data are shown in Figure 5.7, where the means and ranges are plotted for each station. These indicated that the upper stretch of the river, as far as station 4 upstream of Leek, was of good water quality. Below the discharge from the chemical works at Leek, the increase in BOD and decrease in DO at station 5 indicated an organic discharge, but the absence of any increase in nitrogen, either ammonia or nitrate, confirmed that this was not sewage effluent. The entry of the Leek sewage works discharge was however indicated clearly by all parameters at station 6, but the discharge from the paper mill had less effect at station 7.

FIGURE 5.7 River Churnet: Current velocity and chemical data 1977-78 means and ranges

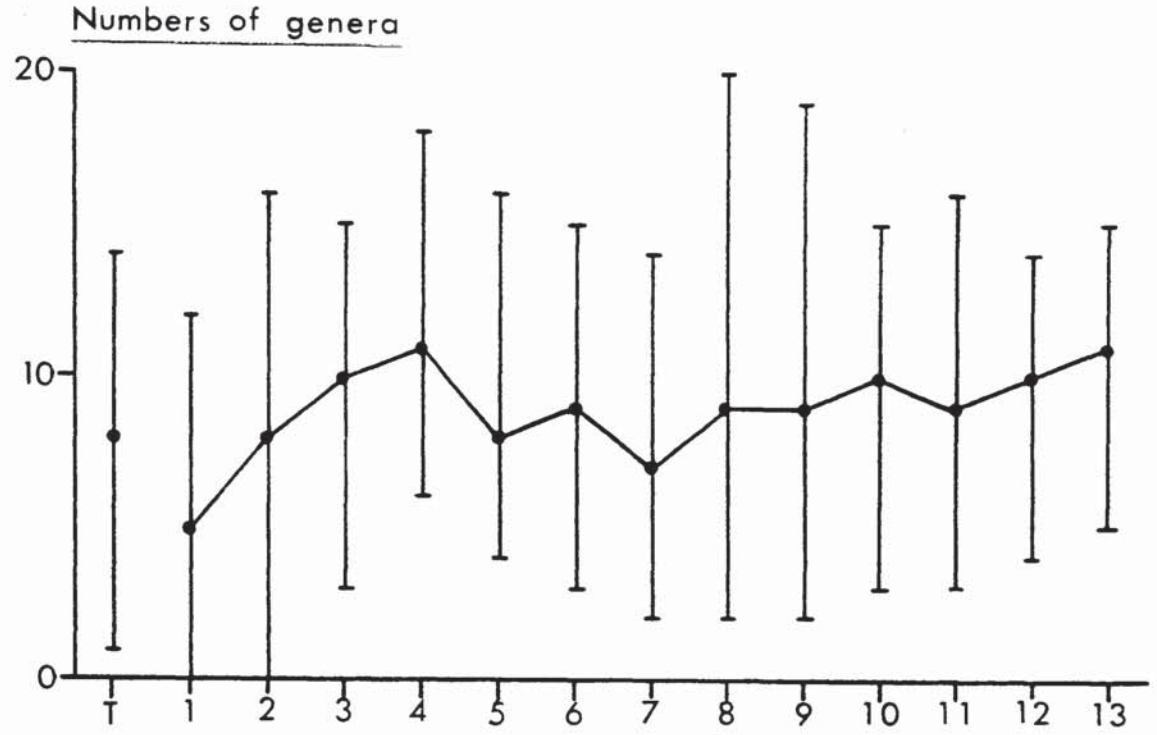


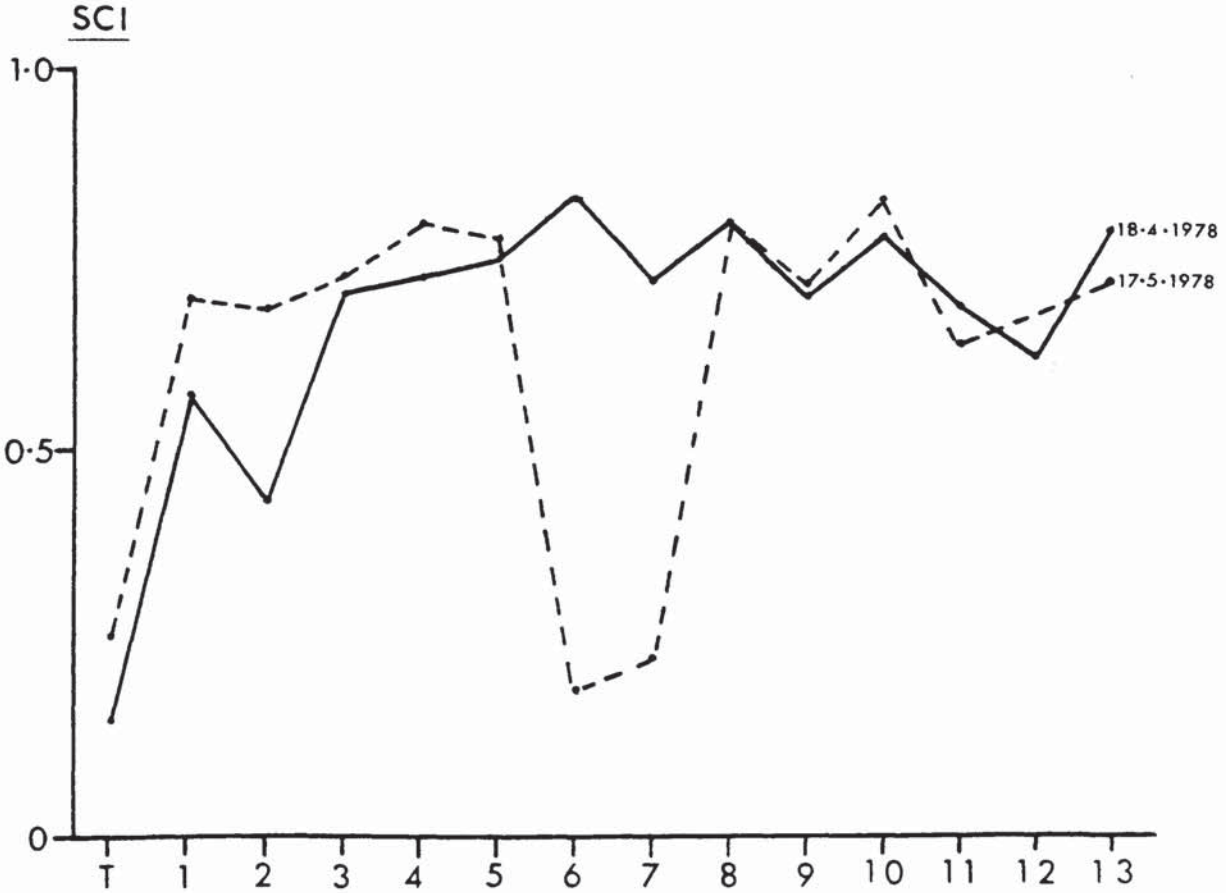
At station 8, a decrease in BOD and ammonia and an increase in DO indicated a considerable degree of recovery from organic pollution, whilst the metals data (Appendix Table A1.) suggested that copper levels were much lower than in previous years, ranging from 0.012 to 0.06 mg l^{-1}. The remaining portion of the river, downstream from station 8, was found to be nutrient enriched but otherwise of good quality.

The results of the biological surveys are shown in Figures 5.8 to 5.10. The mean numbers of genera (with ranges) for each station are plotted in Figure 5.8. These numbers increase steadily from station 1 to station 4, probably reflecting increasing physical stability, station 4 being characterized by a stable substratum and a relatively low and stable current velocity regime. A marked fall in mean numbers of genera was found at station 5, below the chemical works, whilst a slight increase was found at station 6, below the Leek sewage works discharge. Mean numbers of genera fell once more at station 7, downstream from the paper mill, but a progressive increase in mean numbers took place subsequently from this station through to station 13 at the mouth of the river. Except at the upstream stations, where physical stresses such as scouring were suspected to result in low numbers of taxa, the mean numbers of genera seemed to reflect water quality, with a depression in numbers in the polluted middle section of the river followed by a gradual increase as recovery took place. The relatively wide range in numbers of genera found at all stations reflects seasonal variation.

The samples collected on the two consecutive trips of 18th April and 17th May, 1978, were used to prepare permanent diatom

FIGURE 5.8 River Churnet: Numbers of genera (monthly means and ranges for entire study) and Sequential Comparison Index (April and May)





mounts (Section 4.3), and these in turn were employed to evaluate the Sequential Comparison Index (Cairns et al., 1968) for each station. The method is described in Section 3.2.2.3 - a total of 200 individuals was counted from each preparation, and the results are plotted in Figure 5.8. In April, the index gave low values at stations 1 and 2, but higher and relatively stable values at the other stations. The following month, very similar values were obtained except at stations 6 and 7, where the index fell to a very low level. This seemed to occur because the samples from these stations were dominated by the diatoms Synedra ulna and Surirella ovata (Table A2.8), and hence relatively few "runs" were counted. No physico-chemical evidence was found to account for this phenomenon. It is suspected that the SCI responds predominantly to the equitability component of sample diversity, and that a low value will be obtained from samples dominated by one taxon irrespective of the total numbers of taxa present. The total numbers of genera recorded from stations 6 and 7 on 17th May were in fact comparable to the other stations.

Figure 5.9, shows the occurrence of selected taxa at each station, based on data obtained throughout the entire period of the study. For each taxon, the total number of occurrences at each station throughout the study is represented by the shaded portions of the histograms. Since each taxon was also given an abundance rating from 1 to 5 (Section 4.3), it was also possible by totalling these scores, to obtain a relative abundance value for each station - these are represented by the full histograms. In this way, the degree of association between particular taxa and particular stations can be visualized.

For each species at each sampling station :

Total area of column represents
total abundance rating

Shaded area represents number of
sampling occasions on which it occurred.

(see text p. 162).

FIGURE 5.9 River Churnet: Distribution of major taxa

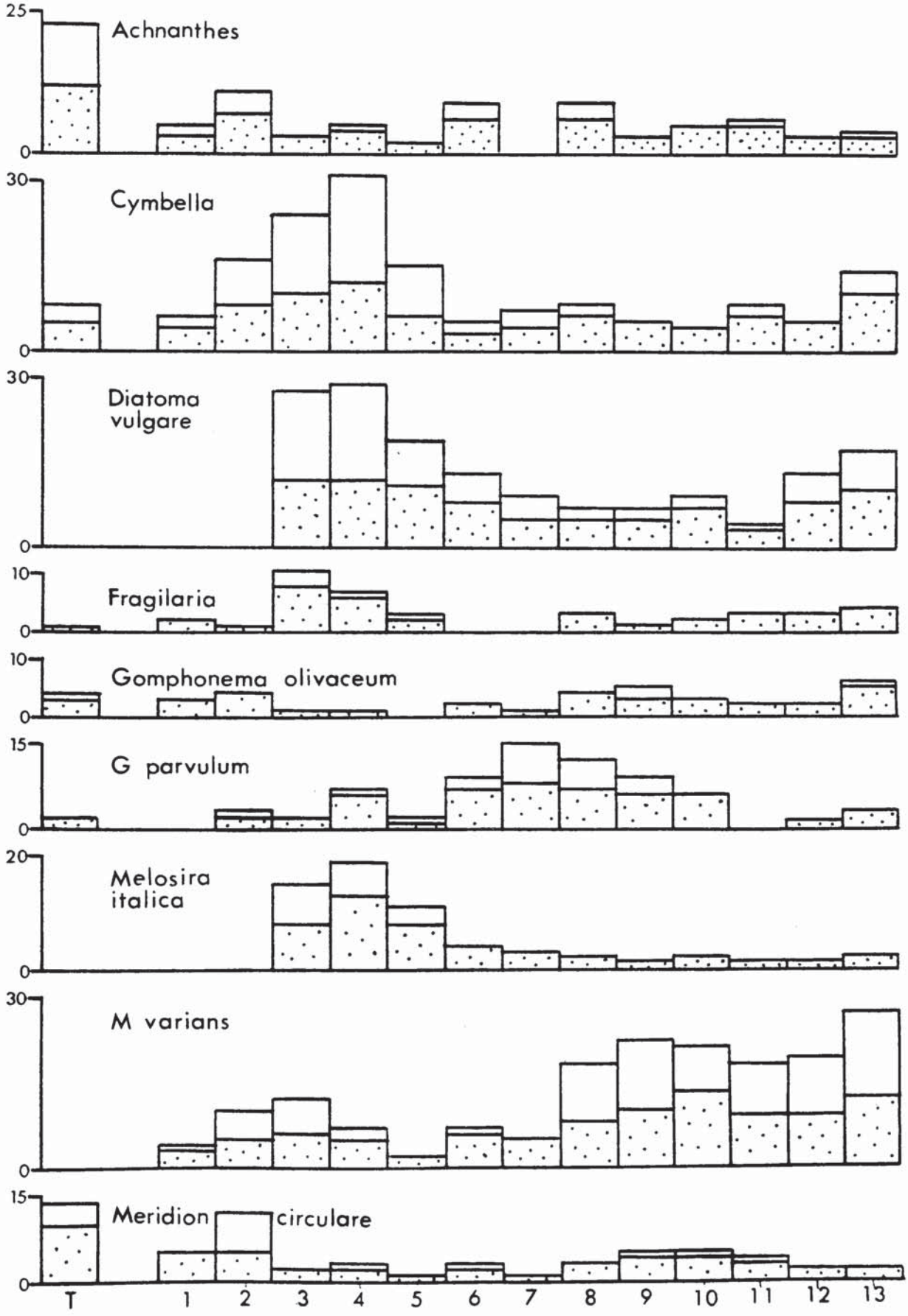


FIGURE 5.9 continued

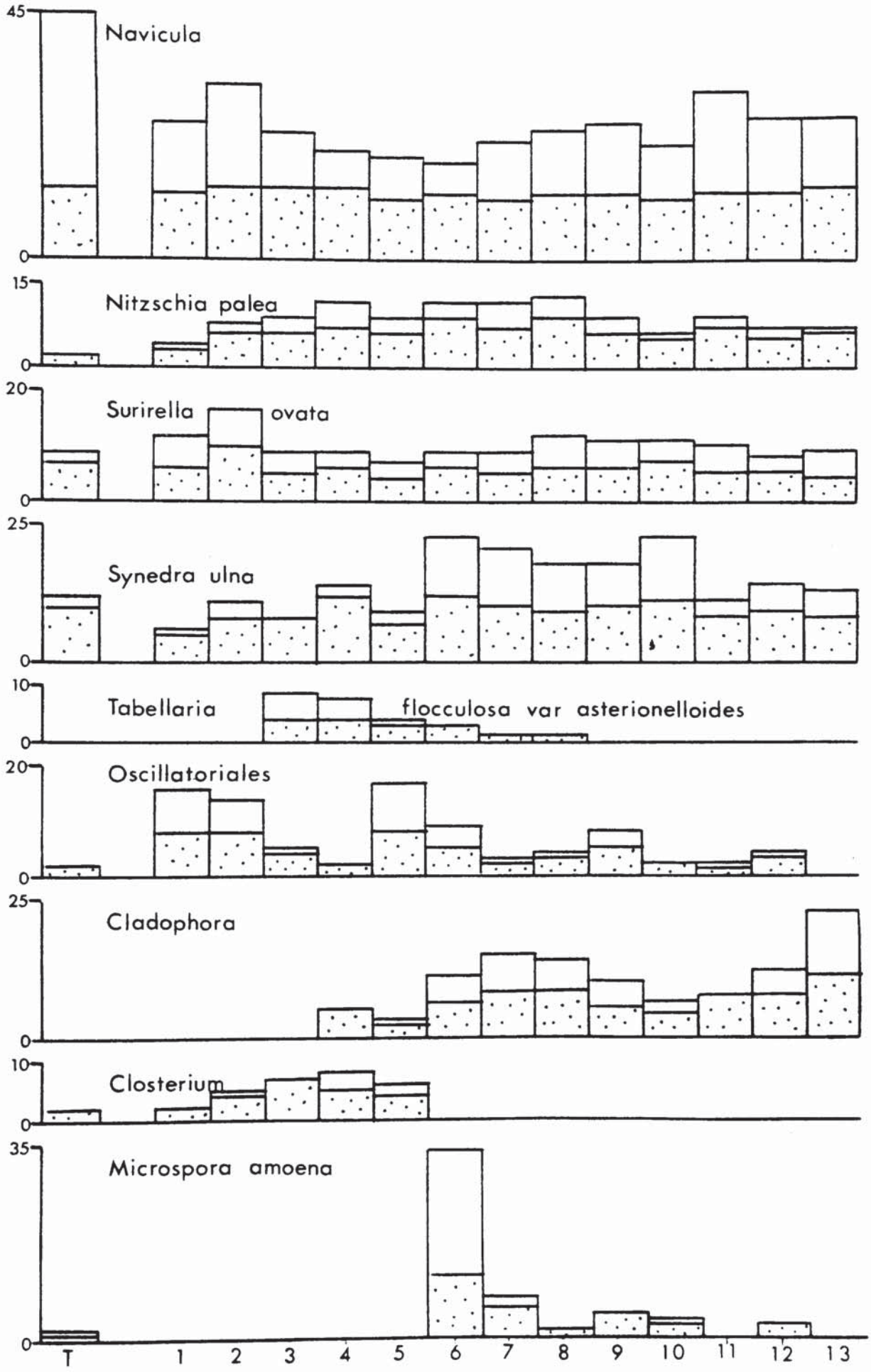
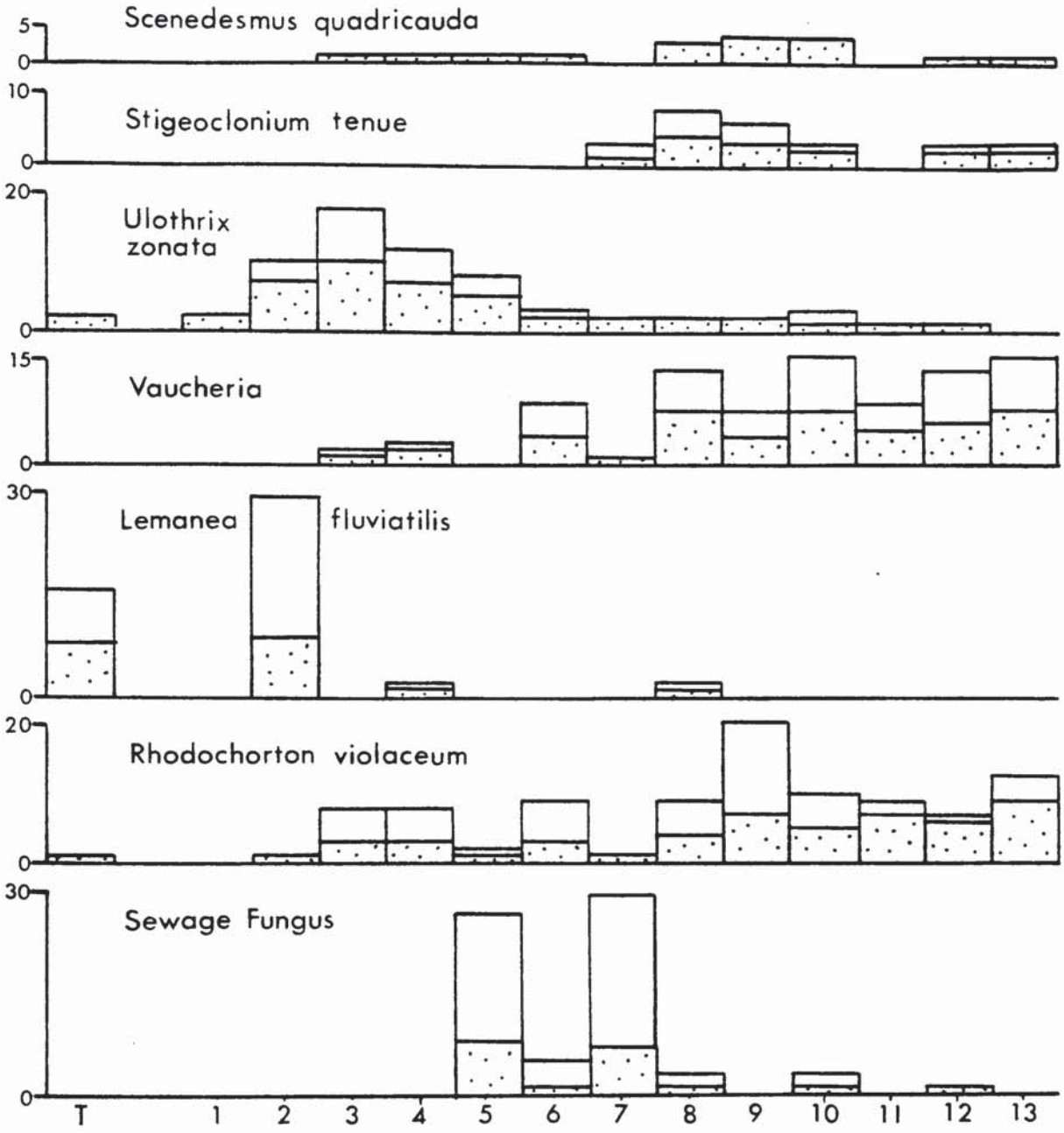


FIGURE 5.9 continued



A number of interesting trends emerge from these data. Forms such as Melosira italica and Tabellaria flocculosa var. asterionelloides are planktonic and were derived from the reservoir, making their first appearance at station 3 and then gradually declining in importance at the downstream stations. Other species were particularly associated with certain stations (Lemanea fluviatilis with station 2, Microspora amoena with station 6, and Rhodochorton violaceum with station 9), whilst still others were ubiquitous in the river, e.g. Cymbella spp., Gomphonema olivaceum, Melosira varians, Meridion circulare, Navioula spp., Nitzschia palea, Surirella ovata, and Synedra ulna. Some genera were absent only at the most polluted stations (Achnanthes spp. at station 7, and Fragilaria spp. at stations 6 and 7), whilst sewage fungus proved to be a reliable indicator of the organic inputs above stations 5 and 7. Stigeoclonium tenue seemed to have an affinity for stations 8 and 9, below the copper works. It seems possible that this species, widely considered to be tolerant of metal pollution, still remains here although the discharge is no longer serious.

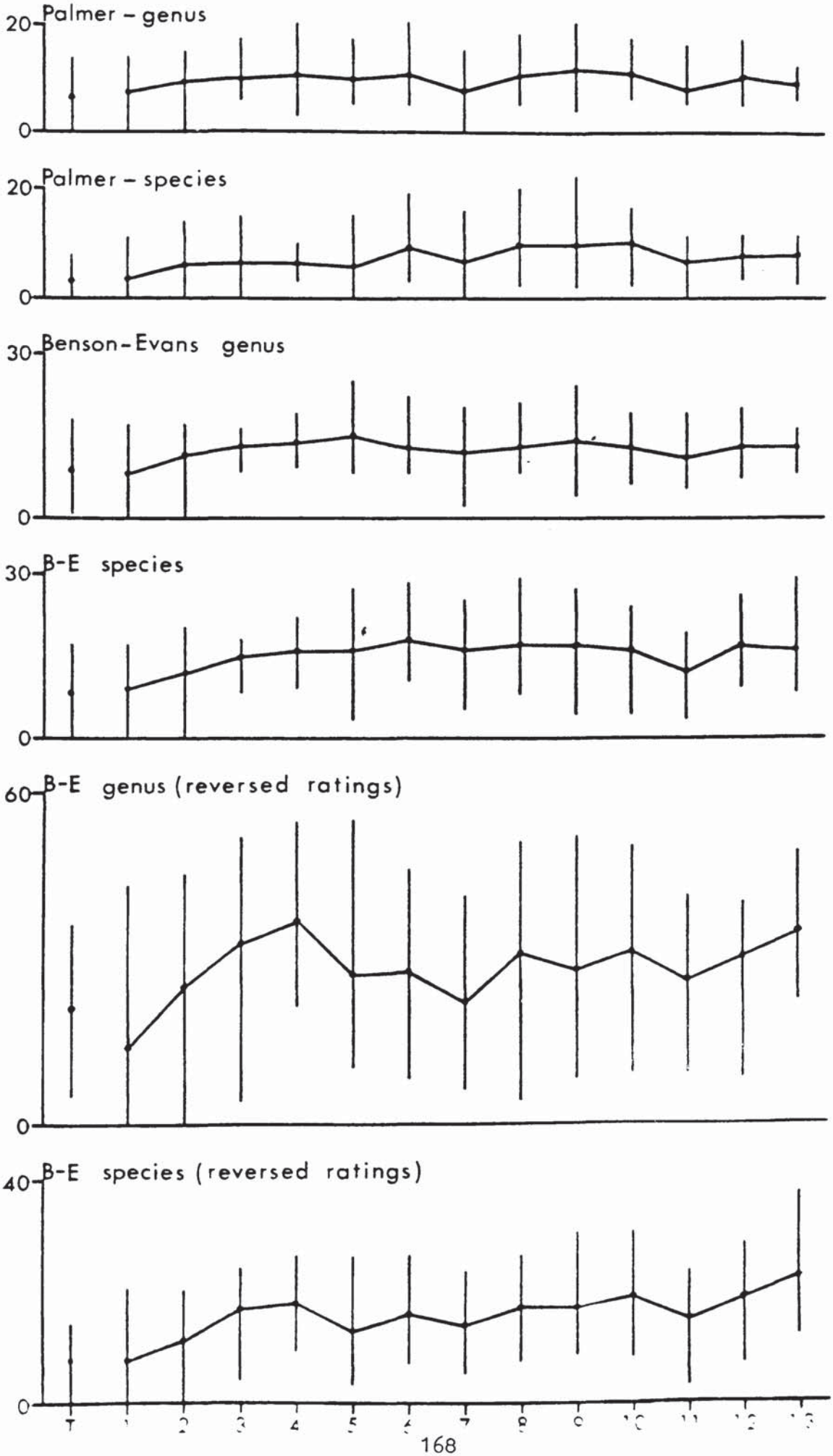
Gomphonema parvulum and Nitzschia palea, widely recognized as indicators of organic enrichment, increased in importance in the middle section of the river, whilst Cladophora, Vaucheria and Melosira varians occurred increasingly in the lower section, probably reflecting increasing nutrient enrichment. Few taxa could be said to be characteristic of the unpolluted upstream stations, although Cymbella spp., Diatoma vulgare and Ulothrix zonata seemed to be particularly associated with stations 3 and 4. Stations 1 and 2 were subject to relatively severe physical

stress (high current velocities, bed roughness, turbulence and probable substratum instability), but a range of clean water forms not included in Figure 5.9 were encountered sporadically at these sites, e.g. Diatoma hiemale, and species of Eunotia and Pinnularia (Table A2.8). During the cold early months of the year in both 1977 and 1978, the stones at station 1 were found to support a well-developed golden-brown mucilaginous coating. The organism involved evaded positive identification, and is listed as "indeterminate" in the Appendix tables, but is thought to have been a Chrysophyte. Whitton (1972) has also reported that palmelloid growths of Chrysophyta are sometimes abundant in upland streams in north-east England when temperatures are only just above freezing.

The Churnet data were also processed using the original Palmer Index (generic and specific) and the modified Benson-Evans versions (Section 3.2.2.3). The results are plotted in Figure 5.10. All indexes were found to be relatively insensitive to water quality, with the exception of the reversed rating Benson-Evans generic index, which showed an increase up to station 4, a depression in the polluted middle section of the river and a subsequent recovery. This seems encouraging, as the index only requires identification to the generic level, and no quantitative estimation of the abundance of different taxa is required. It is however interesting, and perhaps a little discouraging, to note that the shape of this curve is almost identical to that showing simple numbers of genera only (Figure 5.8).

The Churnet survey indicates that the river benthic algae are perhaps most useful at this relatively local level, where

FIGURE 5.10 River Churnet: Palmer Indexes (monthly means and ranges for entire study)



several physically comparable riffle stations can be selected on one river in relation to known discharges, and the natural substrata can be sampled directly and at regular intervals over an extended time period. The occurrence of key taxa such as sewage fungus, Stigeoclonium and Cladophora may still be important, but it may also become possible to recognise trends in the occurrence and abundance of other taxa within the system that may be related to water quality. No further processing of data may be necessary or even particularly helpful in the recognition of such trends.

5.4.4 The Severn, Wye and Nene

It is convenient to consider these three rivers together, since in the reaches studied (Figure 5.1), they are all deep with few or no riffles. Thus, riffle sites were accessible at the three Nene stations only during periods of relatively low flow: in fact, the riffle at station 1 was inaccessible on all sampling occasions, and those at stations 2 and 3 were accessible on only three occasions, from March to early June. The riffle and Bewdley on the river Severn is the last before the river joins the sea, and it too was accessible on only three occasions, in July, August and September. At the two river Wye stations, no riffle sites were present at all.

The chemical data (Table 5.4) show the Severn and the Wye to be good quality rivers, with few marked water quality differences between the two stations on each river. The Severn had generally higher nitrate levels than the Wye, but in the Wye there was a decrease in BOD and an increase in nitrates at station 2, this probably reflecting recovery from the entry of the

TABLE 5.4 Rivers Severn, Wye and Nene 1977 Chemical Data (mg l^{-1}) Means and Ranges

R. Severn

St^n.	Data	SS	DO	BOD	NH_3	NO_3
1	WA	33.0 (6.0-180.0)	11.4 (9.4-15.6)	2.5 (1.0-5.5)	0.1 (0.1-0.4)	4.6 (1.5-9.6)
2	WA	35.0 (8.0-151.0)	11.7 (11.1-12.8)	2.8 (1.3-7.0)	0.2 (0.01-0.5)	5.5 (1.6-9.2)

R. Wye

St^n.	Data	SS	DO	BOD	NH_3	NO_3
1	WA	22.5 (4.0-99.0)	10.4 (9.4-12.5)	2.2 (0.7-5.7)	0.1 (0.01-0.23)	1.3 (0.8-1.76)
2	WA	29.4 (4.0-145.0)	10.9 (8.4-13.0)	1.6 (0.4-3.3)	0.09 (0.01-0.26)	3.3 (1.0-6.9)

R. Nene

St^n.	Data	SS	DO	BOD	NH_3	NO_3
1	Aston	10.0 (4.0-14.0)	10.9 (8.8-13.8)	- -	1.1 (0.75-1.35)	10.0 (5.8-12.7)
	WA	15.0 (5.0-29.0)	9.1 (1.6-12.7)	6.9 (4.1-13.5)	1.3 (0.03-4.0)	13.8 (10.5-16.7)
2	Aston	12.0 (6.0-20.0)	10.4 (7.9-12.4)	- -	1.4 (0.85-2.1)	12.0 (7.1-15.6)
	WA	15.0 (5.0-31.0)	9.0 (4.7-12.3)	10.5 (2.0-27.0)	1.29 (0.45-2.5)	13.4 (11.7-17.7)
3	Aston	16.0 (6.0-34.0)	11.7 (9.6-15.1)	- -	0.96 (0.5-1.25)	10.5 (7.0-14.0)
	WA	17.0 (2.0-78.0)	11.2 (7.5-14.3)	4.4 (1.2-12.5)	0.31 (0.05-2.4)	13.6 (6.8-19.6)

WA = Water Authority

Hereford sewage works effluent immediately above station 1. The Nene was generally of poorer quality, owing to the discharge of various sewage effluents upstream of stations 1 and 2, but the increase in DO and decrease in BOD and ammonia at station 3 indicated a considerable degree of recovery.

The biological results (Tables A2.9 to A2.11) were very disappointing, owing to the general paucity of data from the natural substrata, and the generally poor performance of the Polythene strips. Once again, the presence of Cladophora, particularly in the Severn and the Nene, was probably significant in relation to nutrient status. The complete absence of data from natural substrata in the Wye means that it becomes necessary to rely on data derived from the artificial substrata, but these were very disappointing. The strips were rarely colonized extensively, and then only by a small range of ubiquitous diatoms such as Cocconeis placentula, Melosira varians and Navicula spp,.

5.4.5 The Yorkshire and Wessex Rivers

It is again convenient to consider the isolated stations on the Foss, Don, Bristol, Avon and South Drain together, since each is of different character and water quality, and the data are very limited and fragmentary.

Chemical data are presented in Table 5.5. The Foss was a small river probably recovering from mild organic enrichment. The presence of Cladophora in the riffle again reflected enhanced nutrient levels, and the strips attracted the familiar range of

TABLE 5.5 Rivers Foss, Don, Avon and South Drain 1977
Chemical Data (mg l^{-1}) Means and Ranges

R. Foss

Data	SS	DO	BOD	NH_3	NO_3
WA	21.0 (6.0-69.0)	9.9 (6.1-12.4)	2.5 (1.6-3.7)	0.1 (0.1-0.2)	14.3 (0.6-22.1)

R. Don

Data	SS	DO	BOD	NH_3	NO_3
WA	28.0 (10.0-83.0)	7.6 (4.3-11.8)	6.8 (6.8)	11.6 (2.9-19.6)	6.1 (4.6-8.5)

R. Avon

Data	SS	DO	BOD	NH_3	NO_3
WA	28.0 (3.0-230.0)	- -	3.7 (1.6-10.8)	0.4 (0.08-1.0)	6.6 (4.7-12.5)

South Drain

Data	SS	DO	BOD	NH_3	NO_3
Aston	11.7 (6.0-17.0)	8.8 (4.3-14.3)	- -	0.86 (0.5-1.2)	2.4 (0.05-5.4)

WA = Water Authority

common diatoms. The Don was organically polluted, with relatively low DO but high BOD and ammonia levels. The natural substratum was not sampled, but the strips yielded taxa characteristic of organically enriched waters, particularly in May, when all three strips were found to support the classic Gomphonema parvulum, Nitzschia palea and Stigeoclonium tenue association. This was less apparent on subsequent visits, however, with Nitzschia being absent in July, and Stigeoclonium absent in August.

Of the Wessex rivers, the Avon was large and deep with variable current velocity, whilst the South Drain, a drainage dyke, was relatively shallow with very little flow at most times. No riffles were present at these stations, and the pool sites themselves were never accessible for direct sampling. In the Avon, the Polythene strips supported a relatively diverse range of diatom taxa in August, but fewer taxa and smaller populations were recovered on subsequent occasions. A smaller range of taxa was taken from the South Drain, and perhaps the most interesting distinguishing feature was the presence of the encrusting form Gongrosira on the strips in August.

5.4.6 Analysis of Polythene Strip Data

The data obtained from the Polythene strip samplers were very fragmentary, and the quantitative evaluations were further considered to be unreliable, exhibiting a great degree of variability. It was therefore decided to process these data as a whole, considering the qualitative element (i.e. presence or absence) only. A summary of these data is presented in Table

5.6. For each station, the following information is presented:

(i) Sampling Occasions - the number of separate occasions on which each station was visited in order to retrieve three strips.

(ii) Maximum Number of Polythene Strips - the total number of single strips that should have been retrieved from each station during the survey period, i.e. assuming no losses.

(iii) Total Failures - the total number of single strips that failed to yield data for any reason, including loss as well as failure to become colonized.

(iv) For each taxon, the number of times it was encountered on one or more strips on each separate sampling occasion, i.e. the number of times it was found at each station.

Approximately 46% of all strips failed to yield results. The reasons for this high failure rate were various - some were simply lost, whilst others were victims of fluctuating water levels, being either stranded above the water surface in times of low flow, or inaccessible in times of flood. Many others were recovered successfully whilst still submerged, but were found not to bear attached algal assemblages. The most common reason for this was probably fouling by unwanted drifting material such as plant debris, although in some instances factors such as high current velocity, low light intensity, invertebrate grazing (e.g. by Gastropods) or the mere presence of invertebrate colonists (e.g. Simulium pupæ) may have been responsible. It may also be that in some of the large, slow-flowing rivers, the littoral regions in which the strips were positioned were not rich in suspended algae to act as an inoculum.

TABLE 5.6 Summary of data obtained from Polythene Strip samplers

STATION	Foss	Don	Weaver 1	Weaver 2	Weaver 3	Weaver 4	Nene 1	Nene 2	Nene 3	South Drain	Bristol Avon	Severn 1	Severn 2	Wye 1	Wye 2	Tame 1	Tame 2	Trent 1	Trent 2	Trent 3	Trent 4	Derwent 1	Derwent 2	Mease	Tean 1	Tean 2	Thurnel 6	Thurnel 10	TOTAL
SAMPLING OCCASIONS	3	3	9	9	9	9	7	7	7	4	4	8	8	6	6	9	9	8	8	8	8	8	8	6	10	10	9	9	204
MAX. NO. OF POLYSTRIPS	9	9	27	27	27	27	21	21	21	12	12	24	24	18	18	27	27	24	24	24	24	24	24	18	30	30	27	27	627
TOTAL FAILURES	–	–	6	–	13	12	1	14	11	6	1	3	3	13	5	26	14	15	22	14	18	19	10	14	5	20	20	4	292
Achnanthes spp.			4	2	1	2	1		2	2	2		1		1						1				4		2	5	30
Amphora ovalis			2	5		2					2			1	2							1			2			2	23
Bacillaria paradoxa													1											1					2
Caloneis amphisbaena			1														1					1							3
Cocconeis spp.	3		5	5	2	2	5	1	3	2	2	4	3	2	4			3	1	3	1	2	4	2	5		2		66
Cocconeis kuetzingiana						1																							1
Cocconeis meneghiniana												1																	1
Cymatopleura elliptica			3	1																					1				5
Cymatopleura solea			3	3			1	1													1								6
Cymbella lanceolata			2	1							1		1																5
Cymbella spp.	1		7	2	2	1	4	1	1		2	1	2					1				1			2	1	2	3	36
Diatoma vulgare	1		1	3	1	1	2	1	1	1			1		1		1	1				2	1	1	3	3	1	2	23
Fragilaria capucina			2	1	1	1	3		1	1	1			1	1							1						1	15
Gomphonema angustatum																						1							1
Gomphonema augur									1																				1
Gomphonema olivaceum	1		2	2	1	1	3	1			1	1	1					1				1			3	2	1	3	23
Gomphonema parvulum	1	3	5	4	4	1	4	1	3	2	2	1	1			1	3		2	3		3	2	1	3	3	1	2	56
Gyrosigma spp.			3	2		1	2				3	3	3		1						1								19
Melosira italica																											1		1
Melosira varians			6	3		4	4	1	2	1	4	4	8	2	2		2	1		1	1	3	1	1	1		1	5	58
Meridion circulare							1	1																	1	1	1		5
Navicula spp.	2	1	7	8	4	4	7	2	3	2	3	6	8	2	5		1			1	1	4	1	2	6	2	1	6	80
Nitzschia acicularis							2					1	2										1					1	7
Nitzschia communis									1	1	1																		3
Nitzschia linearis			4	3		1			1		2		2		1		1			1				1	1		1	4	23
Nitzschia palea	1	2	6	5	4	2	5		3	2	4	5	5		3	1	1	1	1	2	2	1	1		3	2		5	67
Nitzschia recta			1																										1
Nitzschia sigma			1		1																							1	3
Nitzschia sigmoidea			4	4		3	1		1		1	2	2								1	1			1		4	25
Nitzschia sublinearis			1	1		1	1	1	1	1		1	1		1										1		2	13
Rhoicosphenia curvata	3	1	5	4	2	2	4		2	2	2	4	2		2		1	5	2	4	2	2	4		6	1		1	63
Synedra acus											1																		1
Synedra ulna	1	1	6	4	1	4	4	2	1	1	3	2	4	1	1	1	1			2		2	2	1	2	2	2	6	57
Chamaesiphon sp.																													2
Oscillatoria sp.			1										1									1							1
Ankistrodesmus sp.							1																						1
Characium spp.	1	2					1			1							2			2			1						10
Chlorococcum sp.										1																			1
Cladophora sp.																				1									1
Closterium sp.			1										1																2
Gongrosira sp.										1																			1
Encrusting Green	2	2	3	3	4	1	4	1	4	2	1	4	4	1	3		3	1	2	2	3	5			1			1	57
Pediastrum spp.												1		1															2
Scenedesmus spp.											1	1	2																18
Stigeoclonium spp.			5	2	1	2	3			1						1	3		1	2									14
Ulothrix sp.		2	1		1		1	1				1										1							1
Ulvella sp.	1																												1
Carchesium polypinum				3																									3
Vorticellids							1	1									2												4
TOTAL (TAXA)	12	8	28	23	15	21	24	13	17	17	19	19	23	8	15	4	10	7	6	13	10	17	12	8	16	8	11	19	

NB. Figures indicate the number of separate sampling occasions on which each organism was recorded at the sampling stations.

Loss of strips as a result of vandalism or other unwarranted removal was comparatively rare, since some care was taken to select sites not readily accessible to the public, and to ensure that the strips were inconspicuous when in position. It should be mentioned however, that satisfactory anchorage was not always readily achieved, owing to difficult field conditions, particularly where bed characteristics made it difficult to drive the metal anchoring rods firmly into position.

The vertical total column of Table 5.6 gives, for each of the taxa listed, the total number of separate occasions on which it was encountered at all the stations sampled throughout the survey. The ten most frequently encountered forms, in order of decreasing importance, were Navicula spp., Nitzschia palea, Cocconeis spp., Rhoicosphenia curvata, Melosira varians, Synedra ulna, unidentified encrusting green algae, Gomphonema parvulum, Cymbella spp., and Achnanthes spp. The genus Navicula is taxonomically very difficult, and might be of greater value for surveillance purposes if reliable identification to the species level could more readily be achieved. This is also true of a number of other genera, particularly Nitzschia, Cymbella and Achnanthes.

In many instances, the unidentified encrusting green forms probably represented the prostrate portions of various species of Stigeoclonium, as discussed by Butcher (1932a). It is also interesting to note that on only one occasion (28th July, 1977, at Trent station 3) was Cladophora found to be growing attached to a Polythene strip.

In general, then, the Polythene strips tended to attract a relatively small range of common and widely distributed diatom taxa, probably representing that fraction of the river plankton derived from the bed in the shallower reaches (Butcher, 1932b). These data would be expected to be of strictly limited value for water quality surveillance purposes, precisely because the organisms involved are so common and ubiquitous (at least at the level of taxonomic precision possible in the survey), and because they do not seem to form well-defined assemblages on the strips that might reflect water quality at the sampling point itself.

In order to test this hypothesis further, the data presented in Table 5.6 were subjected to cluster analysis using the CLUSTAN 1A package implemented at the University of Aston for the ICL 1904S computer. The principles of cluster analysis were introduced briefly in Section 3.2.2.3, and are discussed in greater detail by Everitt (1974) and Lance and Williams (1967). The technique involves the computation of a matrix of similarity coefficients in such a way that each station in the survey is compared directly with each of the others, in terms of the taxa present, and optionally, their quantitative importance. This matrix is then processed systematically by the computer and displayed graphically in the form of a dendrogram in which stations are linked together hierarchically, those showing the greatest affinities tending to form distinct groups or clusters, at relatively high levels of similarity, but with all stations linking together eventually at the lower levels of similarity.

For the purposes of the present exercise, only binary data

(i.e. presence or absence of each taxon at each station) were used for three of the most common clustering strategies - Nearest Neighbour, Furthest Neighbour, and Group Average. In all these strategies, clusters are combined when the "distance" between them is defined as minimal. Nearest Neighbour is the oldest of the conventional hierarchical strategies, the distance between two clusters being defined as the distance between their closest elements, one from each cluster. It is a "space-contracting" strategy, that is, on formation a cluster will appear to move nearer to some or all of the remaining elements, thereby increasing the chances of an individual element joining a pre-existing cluster rather than acting as the nucleus of a new one. The dendrogram therefore has an undesirable tendency to form chains.

Furthest Neighbour is the exact antithesis of Nearest Neighbour in that the distance between two clusters is now defined as that between the most remote pair of elements, one from each cluster. It is "space-dilating", that is, clusters appear to recede on formation and growth, and individual elements not yet in clusters are more likely to form the nuclei of new clusters. The strategy is inherently likely to produce non-conformist clusters of peripheral elements and is used when a relatively intense clustering pattern is desired.

In the Group Average strategy, the distance between two clusters is defined as the average of the distances between all pairs of elements, one from each cluster. This is a "space-conserving" strategy, showing no marked tendency toward contraction or dilation. All the strategies employed have the desirable

properties of being combinational (the hierarchy develops in a cumulative manner) and compatible (the distance measures are consistent throughout).

The dendrograms are presented in Figure 5.11. As expected, a progressively more intense clustering pattern is produced from Nearest Neighbour through Group Average to Furthest Neighbour, but this does not seem to be clearly related to the broad water quality categories represented by the different stations, and no general trends emerge. The main exception is the organically polluted Don, Tame 1 and Trent 2 group. This suggests an underlying uniformity in the original data, with detailed differences between stations being of little significance except under conditions of relatively severe water quality deterioration.

Finally, an attempt was also made to compare the Polythene strip data with the corresponding riffle data. Table 5.7 records the occurrences of twelve of the commoner taxa on both substratum types at the same stations, on all the sampling occasions throughout the survey on which simultaneous sampling of both was successfully achieved - a total of 58 occasions in 11 of the rivers. This gives some indication of the extent to which the data derived from both types of substratum differ, even qualitatively, at the same stations, i.e. under similar water quality conditions. Most of these common taxa occurred more frequently on one substratum type than on the other, and on many occasions, simultaneous occurrence of the same taxa on both substratum types at the same stations simply did not occur. This clearly leads to further difficulties in the interpretation of data derived from

artificial substrata, since the significance of these data in relation to water quality will be entirely different from those derived from natural substrata.

FIGURE 5.11 Cluster analysis of Polythene Strip Data
Nearest Neighbour

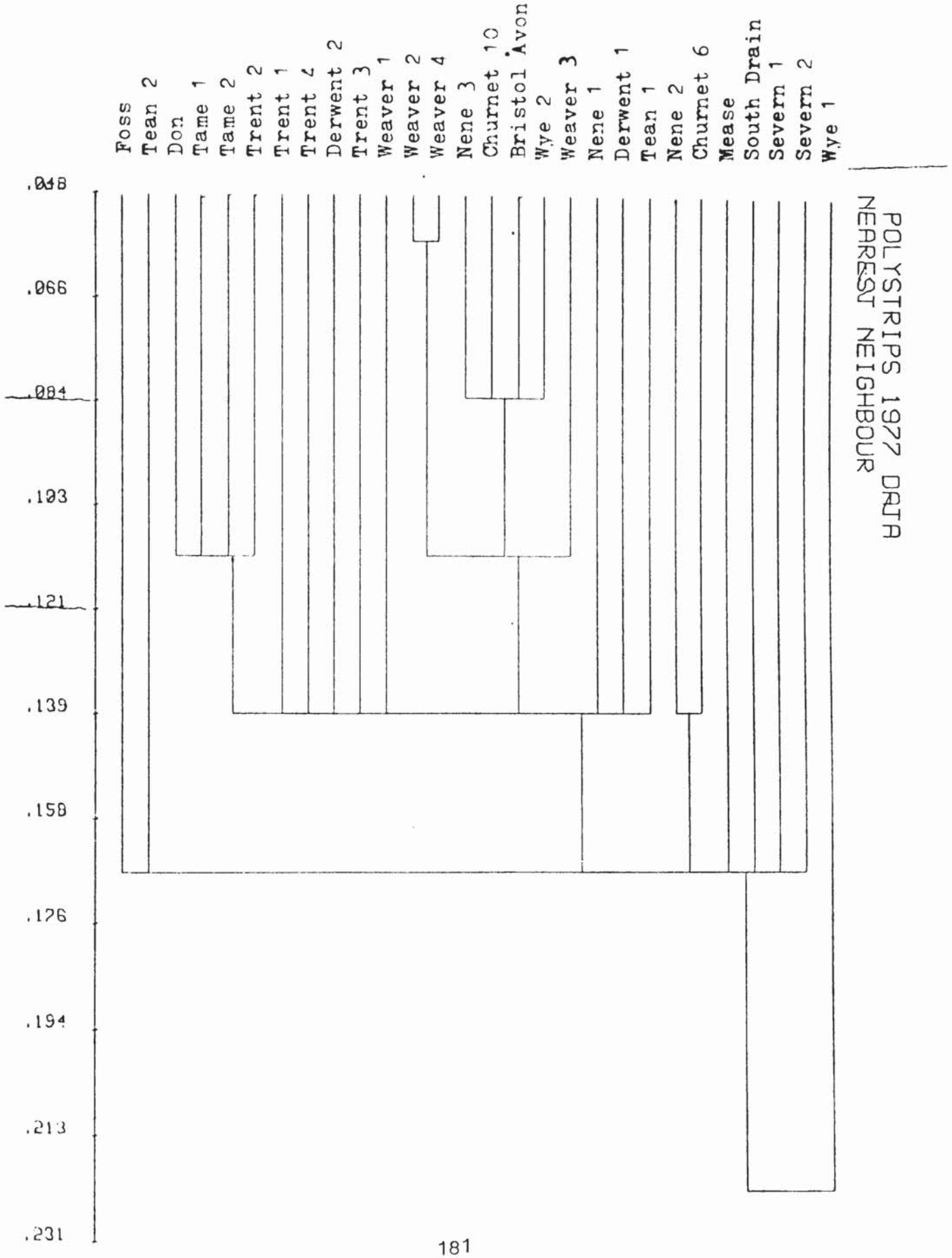


FIGURE 5.11 continued
Furthest Neighbour

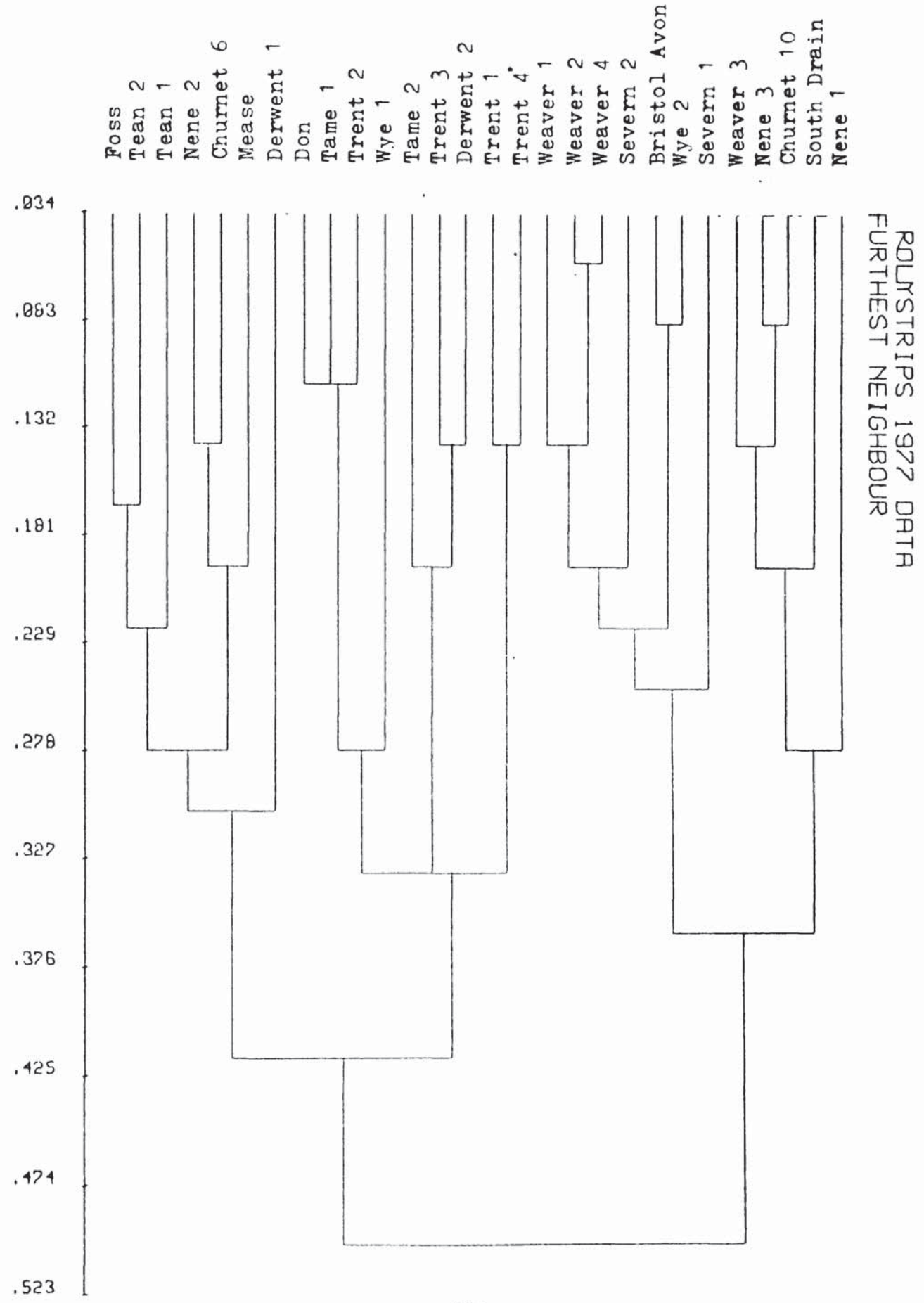


FIGURE 5.11 continued
Group Average

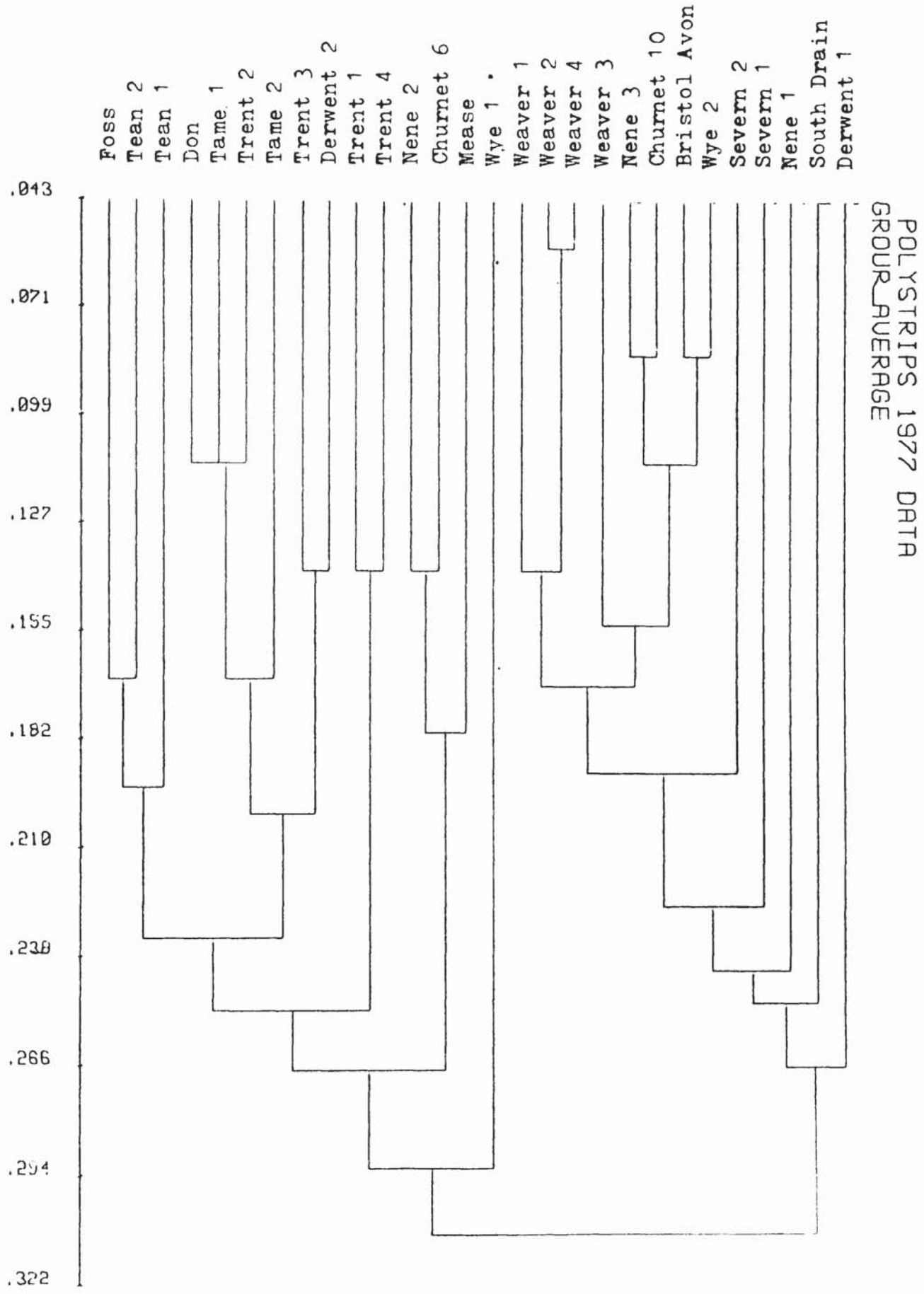


TABLE 5.7 Comparison of occurrences of twelve of the commoner taxa on Polythene Strips and in riffles at the same stations

	Total occurrences	% age occurrence	Total occurrences on strips	Total occurrences on stones	Present on both
Achnanthes spp	20	34.5	16	8	4
Cocconeis spp	31	53.4	29	21	19
Cymbella spp	26	44.8	22	10	6
Gomphonema parvulum	35	60.3	28	20	13
Melosira varians	43	74.1	24	37	18
Navicula spp	52	89.7	37	48	33
Nitzschia palea	49	84.5	30	37	18
Rhoicosphenia curvata	41	70.7	32	35	26
Synedra ulna	45	77.6	27	42	24
Encrusting greens *	22	37.9	21	1	0
Stigeoclonium spp	12	20.7	10	5	3
Cladophora spp	39	67.2	0	39	0

* Genus not determinable.

6. STUDIES ON CLADOPHORA

6.1 Introduction

The filamentous green alga Cladophora has achieved widespread notoriety as a nuisance organism in both lentic and lotic habitats, particularly under conditions of nutrient enrichment or eutrophication. A review of the biology of Cladophora in freshwaters has been presented by Whitton (1970a), although in this account the literature already discussed by Van den Hoek (1963) and by Fjerdingstad (1965) was largely omitted.

The taxonomy of the genus Cladophora is extremely complex and difficult, owing mainly to a high degree of morphological and cytological plasticity. Van den Hoek (1963) recognised nine species from freshwater (excluding brackish) habitats. As Whitton (1970a) observed, the species most often reported from eutrophic freshwaters are C. glomerata, C. rivularis and C. fracta, and of these C. glomerata is referred to much more frequently than the other two. Indeed Blum (1956) suggested C. glomerata to be the most abundant filamentous alga in streams throughout the world.

In rivers with a predominantly stony or rocky substratum, luxuriant attached growths of Cladophora, known popularly as blanket-weed, are frequently found some distance below sewage works discharges, sometimes forming a distinct zone extending for further distances of up to several miles (Hynes, 1960). The seasonal pattern of growth is characteristically bimodal, with maximum crops occurring in early summer and early autumn, but considerable variation has been observed between different rivers

and even in the same river from one year to the next. Large growths may form the most conspicuous feature of the stream bed, attaining a high percentage cover and mean instantaneous standing crops in excess of 150 g m^{-2} dry weight, with values actually exceeding 1000 g m^{-2} for some individual 10 cm^2 quadrats (Whitton, 1970a). As this author pointed out, these values are low in comparison with some of the values quoted for attached angiosperms, but the actual rate of growth of Cladophora can be very high, approaching a doubling every two days under favourable conditions. Increases in filament length as high as 2.5m per day have been recorded, with streamer-like growths reaching a total length of up to 12m (Hawkes, 1977).

Although nuisance growths of Cladophora are well known in rivers, accounts are scattered and mostly not very detailed (Whitton, 1971). Excessive growths may adversely affect recreation and amenity by interfering physically with swimming, boating and angling activity and by creating a habitat unsuitable for fish and fish food organisms. Photosynthesis during periods of rapid growth may lead to oxygen supersaturation by day, but marked deoxygenation may occur at night as a result of respiratory demand. Further oxygen demand may be imposed by the decomposition of large masses of the alga, especially if accumulated organic solids are present. Low oxygen levels would be expected to restrict fish distribution either directly, or indirectly by restricting the distribution of food organisms, whilst severe deoxygenation has been implicated in fish mortality on some occasions. On the other hand, it seems possible that high rates of photosynthesis, leading to elevation of pH values

in only moderately buffered waters, and hence greater toxicity of ammonia, may also have been involved in fish mortality.

Dense growths of macrophytes, including Cladophora, are capable of impeding river flow, leading eventually to drainage problems, flooding and silting. A related problem of special interest is the presence of such growths on river flow measuring structures such as Crump weirs, causing inaccurate flow measurement (Department of the Environment, 1977).

It should also be remembered that large masses of Cladophora may detach and become free-floating, especially after storms or floods; such masses may give rise to further nuisance downstream of the zone of active growth. In addition to causing some of the problems already mentioned, drifting Cladophora masses may become entangled with other plants, defoliating or uprooting them (Hynes, 1960) or, following a return to normal water levels, remaining stranded along the banks or amongst the bankside vegetation (Whitton, 1975). Such masses become particularly offensive with the onset of decomposition in warm weather.

The growth pattern exhibited by Cladophora in most situations probably results from the interaction of several physical, chemical and biological factors (Whitton, 1970a) but as Hawkes (1977) pointed out, although growths of Cladophora occur in rivers upstream of sewage works discharges, it is usually only below such discharges that growths of nuisance proportions occur. It is now generally agreed that obvious increases in growths of Cladophora in the post-war period reflect increased levels of nitrates and

phosphates in rivers, resulting both from increased human population and the more extensive use of fertilizers and detergents. Hawkes (1964) ascribed increases in crops of Cladophora downstream of a sewage works discharge in a tributary of the river Tame (Midlands) to an increaee in the phosphorus concentration from 0.28 to 4.80 mg Pl^{-1}. In a survey of rivers in the Midlands and South-East (Pitcairn and Hawkes, 1973) a positive correlation was found between the standing crop of Cladophora and the phosphorus concentration of the water. In general, rivers having less than 1.0 mg Pl^{-1} supported only modest growths of the alga. There was no such clear correlation with the nitrate concentration, but laboratory culture work, whilst confirming the importance of phosphorus, also indicated an interaction between nitrogen and phosphorus. The long-term field observations and experimental work reported by Bolas and Lund (1974) also suggested a causal relationship between high phosphorus levels and excessive growth of C. glomerata in the Kentish Stour. Hoffman et al. (1974) grew Cladophora, Spirogyra and Vaucheria from the Eau Gallie River (Florida) in laboratory culture, and found phosphorus to be limiting for all three genera. Wong and Clark (1976) attempted to utilize field data directly in the determination of critical nutrient concentrations for C. glomerata in streams in southern Ontario; nitrogen was found not to be limiting, but a growth-controlling phosphorus concentration of only 0.06 mg Pl^{-1} was determined. There is thus considerable evidence to suggest that nutrient enrichment is an important factor in encouraging large crops of Cladophora, indeed Whitton (1975) has stated that the fresh arrival at a site of a large growth of Cladophora would suggest the probability that some form of eutrophication had

taken place. The majority of workers agree, however, that in any one situation several factors may be involved, and for many rivers it will be difficult to predict the times and degree of development of the largest crops.

In view of the common occurrence of large crops of Cladophora, knowledge of its chemical composition and ability to accumulate substances from the aqueous environment is of some practical importance (Sections 1.2.3 and 3.2.2.2). Cladophora has been found to be particularly efficient in accumulating DDT and radioisotopes (Whitton, 1970a) whilst more recently (Whitton, 1979) interest has been shown in the accumulation of metals by Cladophora, and its potential as an aquatic biological indicator or monitor for these ubiquitous pollutants. Wood (1975) placed quantities of approximately 1 gram fresh weight of Cladophora and Ulothrix in Dacron net bags (10 meshes cm^{-1}) and exposed these for short time periods (2 hours or overnight) in several metal-contaminated and control streams in northwestern U.S.A. Although the results of this survey were widely variable and in some cases difficult to interpret, it was apparent that even in the short time periods involved, these small samples were capable of significant accumulation of metals (Cd, Cu, Pb, Zn), in some cases to levels comparable to those found in the indigenous biota. In a laboratory study, Burkett (1975) studied the uptake and release of methylmercury -203 by C. glomerata from the Olentangy River (Ohio). Accumulation was tested at exposure concentrations of 10, 50 and 100 ug l^{-1}. The initial rate of accumulation seemed to be independent of exposure concentration, but in all cases stabilization occurred between days 2 and 8, with concentration

factors at the end of the 16 day experiment ranging from 937 to 1509. Keeney et al. (1976) employed an anodic stripping voltammetry technique for the determination of Cd, Cu, Pb and Zn in C. glomerata from Lake Ontario. Concentration factors ranged from 1.0×10^3 to 49×10^3 for the samples and elements studied. Comparison with data reported by other workers from different localities indicated a remarkable consistency in concentration factors, but the authors stressed the desirability of further survey work to strengthen these preliminary observations.

Unialgal cultures of a range of Cladophora species have been maintained for considerable periods of time (Van den Hoek, 1963; Whitton, 1970a) but comparatively few laboratory autecological studies have been attempted. Whitton (1967) reviewed the earlier literature and discussed the difficulties involved in this type of work. Most of the difficulties appear to be related to the standardisation and replication of materials and techniques, the measurement of growth and the interpretation of results in relation to the field situation. Whitton (1967) further reported the results of shake culture experiments designed to test the effect of various factors widely quoted in the literature as limiting to the growth of C. glomerata in rivers. Similar techniques were later employed (Whitton, 1970b) to investigate the toxicity of Cu, Pb and Zn to a wide range of chlorophytes, including C. glomerata, taken from lotic waters. Pitcairn and Hawkes (1973) employed a flask culture technique to study the role of phosphorus in the growth of Cladophora; the alga was grown both in synthetic media and in natural river water, supplemented for some experiments with known concentrations of phosphorus. Hoffman et al. (1974) found

a river water medium to be the most satisfactory for experimental work on Cladophora, Spirogyra and Vaucheria. In virtually all laboratory studies of Cladophora involving the use of synthetic inorganic media, it has been found necessary for sustained growth to add up to 10% by volume of membrane - filtered natural water or soil water extract. Moore and McLarty (1975) attempted to investigate this phenomenon further, in the hope that the active components of a soil water extract might be discovered. Analysis of soil water extract showed that an organic heat-labile component was significant, and when thiamine was substituted for the extract, it was found to furnish 80% of the stimulation originally induced by the extract. The presence of thiamine in soil water extract was verified, and further investigations suggested an optimum thiamine concentration for C. glomerata of 10 ug l^{-1}.

In concluding this introductory review, it might be said that the factors affecting the growth of Cladophora in freshwaters are still poorly and incompletely known, owing mainly to the complexity of the field situation and the difficulties involved in performing appropriate laboratory experiments. Although best known as a nuisance organism, Cladophora may be of value as a bioaccumulation indicator or monitor for certain waterborne pollutants, particularly metals, but there is a need for further investigation in this area also.

6.2 Studies on the bioaccumulation of metals by Cladophora in the river Tean, Staffordshire

6.2.1 Objectives

Although Cladophora is known to accumulate metals from the surrounding water, published data are fragmentary and comparatively little is known of the extent to which concentration factors vary in space and in time. The objectives of this survey were to study in detail the bioaccumulation of six important metals (cadmium, chromium, copper, lead, nickel and zinc) by Cladophora in a single river. It was anticipated that by sampling several stations over a period of time, any patterns in the spatial and temporal variation of concentration factors for these metals would become apparent. These data could then also be compared more generally with published records from other localities, and in this way the potential role of Cladophora as a bioaccumulation indicator or monitor for waterborne metals might be more readily assessed.

6.2.2 Methods

The river Tean, Staffordshire, flows from Huntley for approximately 15 km through agricultural land to its confluence, northeast of Uttoxeter, with the river Dove (Figure 6.1). The only significant point discharge to the river is from the Blithe Valley Water Reclamation Works at Checkley (National Grid Reference SK 034374). This effluent was known to contain metals of industrial origin as well as those normally associated with

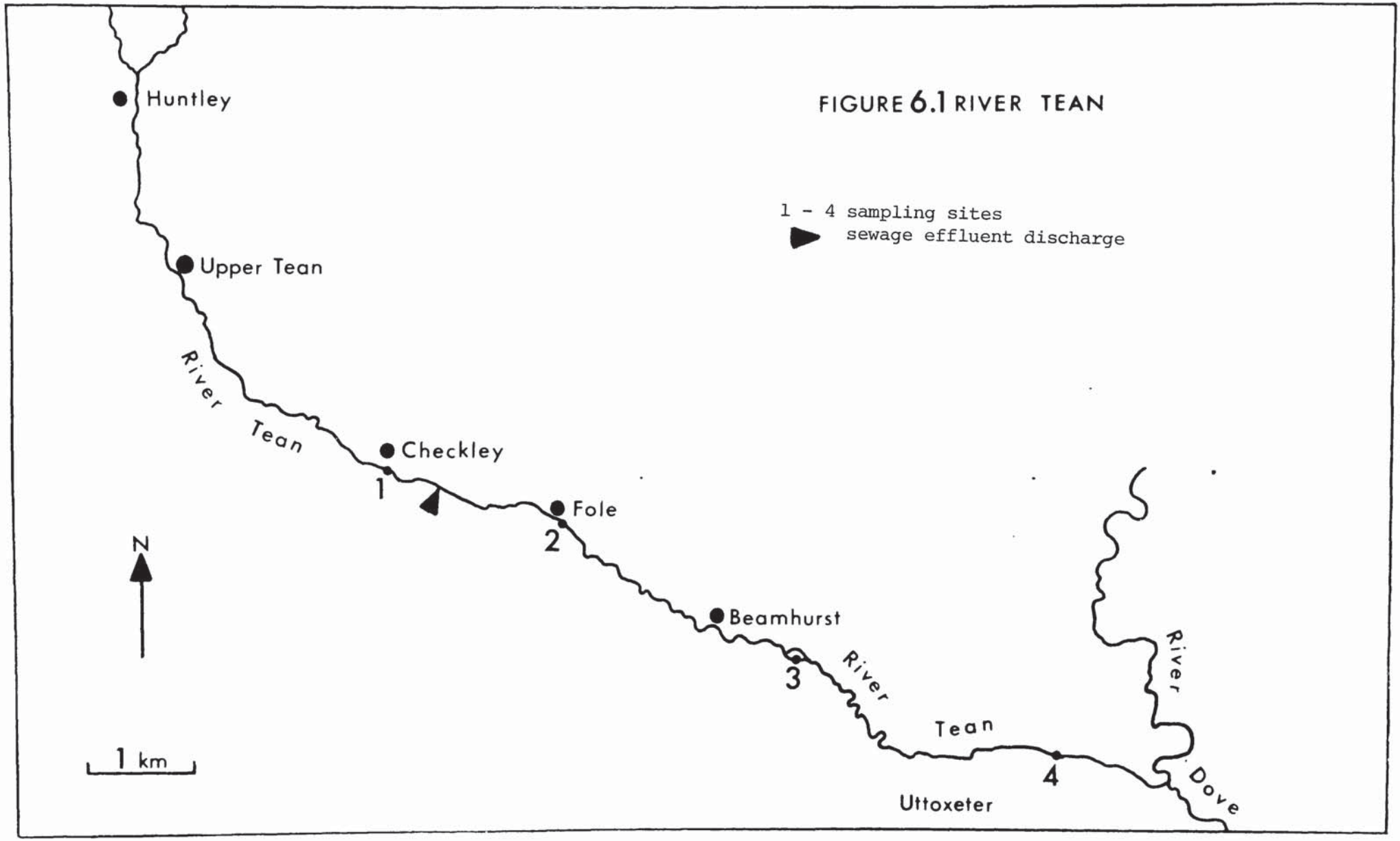


FIGURE 6.1 RIVER TEAN

domestic sewage. It was also known (Sections 4 and 5) that the river was capable of supporting growths of Cladophora both upstream and downstream of the Checkley discharge. Four stations were established at points along the river Tean; Station 1 (SK 028376) was located approximately 0.5 km upstream of the point of entry of the Checkley effluent, whilst stations 2 (SK 046372), 3 (SK 068358) and 4 (SK 093348) were situated at distances of approximately 1.5 km, 4.5 km and 7.5 km respectively downstream of the discharge. All the stations were riffles with relatively stable stony substrata.

Sampling commenced as soon as growths of Cladophora were noticed in the river in 1978 (March 1st, at stations 3 and 4) and continued at intervals of two weeks until July 4th, thus covering the entire spring and early summer growth phase of the alga. On each of the ten sampling dates, water samples were taken from each station for the determination of physico-chemical parameters, including metals. Cladophora samples for the determination of biomass and metal content could only be taken if the alga was present in sufficient quantity at any station.

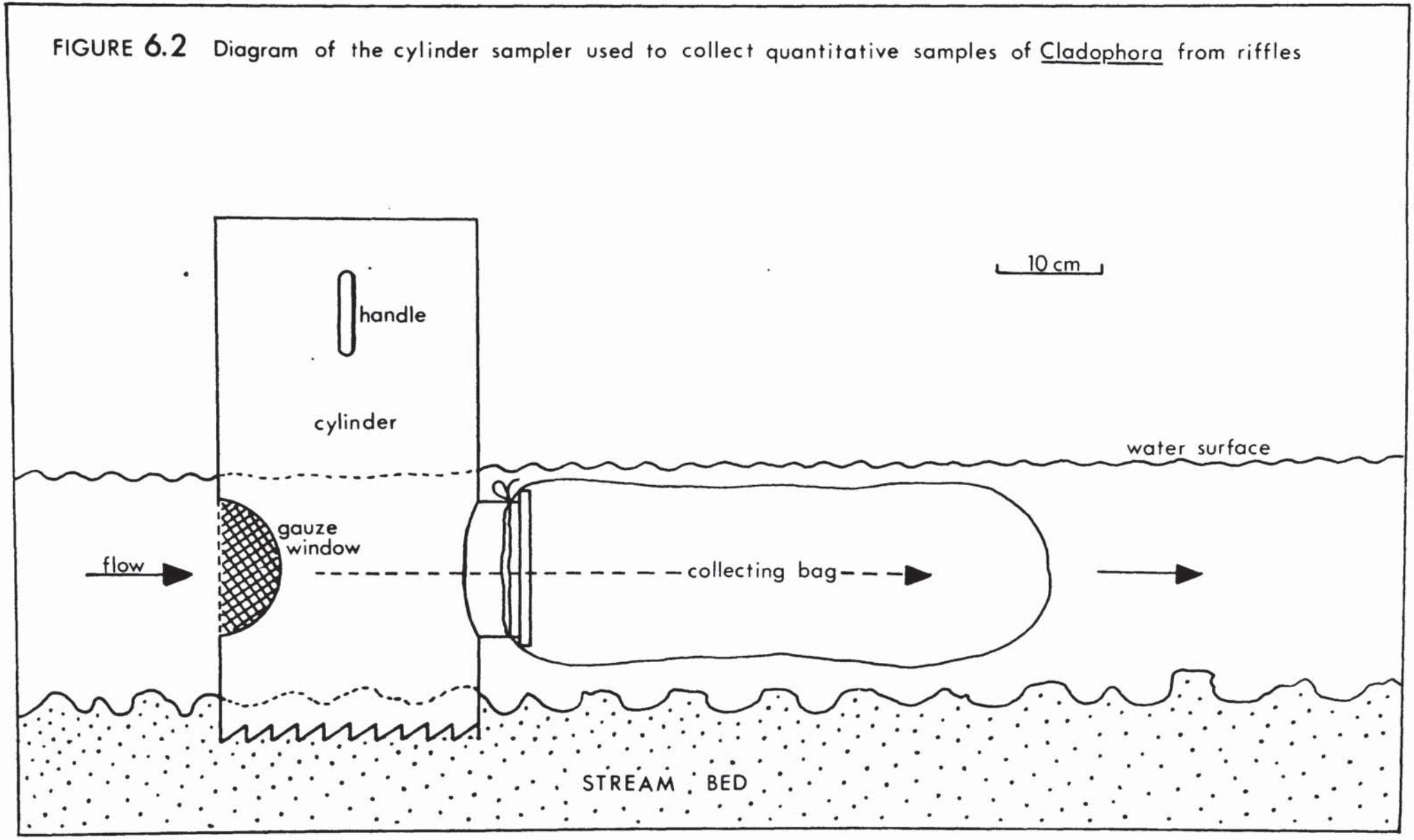
The methods described in Section 4 were employed for the determination of current velocity, temperature, suspended solids, chlorides, alkalinity, hardness, pH, dissolved oxygen, BOD, ammonia, nitrates and phosphates. A Perkin-Elmer 306 atomic absorption spectrophotometer was employed for all the metal determinations. Water samples for metal analysis were collected in 300 ml glass bottles each containing 2 ml of concentrated Aristar hydrochloric acid. In the laboratory, each sample was

shaken and a 250 ml aliquot transferred to a 400 ml Pyrex beaker with 5 ml of concentrated atomic absorption grade nitric acid. The beakers were then transferred to a hotplate in a fume-cupboard, and the digestion mixtures taken to dryness, vigorously at first but more slowly as the volume of liquid decreased. The residue left in each beaker was taken up in 2 ml of 50% Aristar hydrochloric acid and the resulting solution made up to 25 ml with distilled water. Any remaining small quantities of inorganic residue were allowed to settle, and aliquots of the clear yellow supernatant were aspirated directly into the spectrophotometer. Cladophora samples for metal analysis were collected by hand in the field and placed immediately with a minimum of water in plastic containers. Where possible, a large sample of several hundred grams wet weight was collected generally from each station. In the laboratory, each sample was transferred to a shallow white plastic tray where it was cleaned and rinsed thoroughly with distilled water. An attempt was made to remove all extraneous material, leaving only pure Cladophora. After pressing gently by hand to expel excess water, each sample was transferred to a clean evaporating dish and dried to constant weight at 105 ^{o}C. The dry material was then ground to a fine powder using a pestle and mortar. A subsample of 0.5g was weighed directly into a 50 ml Pyrex Erlenmeyer flask, and 15 ml of concentrated atomic absorption grade nitric acid was pipetted on to the powder in the flask. The flasks were closed with small watchglasses and maintained at laboratory temperature until any reaction had subsided completely. They were then transferred to a hot plate in a fume-cupboard and the digestion mixtures allowed to reflux gently for six hours. The watch glasses were then removed and the flasks taken to dryness slowly at low heat. The residue left

in each flask was taken up in 2 ml of 50% Aristar hydrochloric acid and the resulting solution made up to 25 ml with distilled water. Any remaining small quantities of inorganic residue were allowed to settle, and aliquots of the clear yellow supernatant were aspirated directly into the spectrophotometer. A series of five blank determinations, using reagents only, was also carried out. All glassware used in the procedures described above for metal determinations was initially cleaned with IM nitric acid, rinsed thoroughly with distilled water and allowed to air dry in a dust-free atmosphere.

Quantitative Cladophora samples for biomass estimations were collected using a cylinder sampler of the type described by Pitcairn and Hawkes (1973). The sampler (Figure 6.2) was constructed of 18 gauge stainless steel and was approximately 50 cm high with an area of cross section of 0.05 m^2. It was pushed with a rotating action firmly downward into the stream bed in such a way that the oval gauze (stainless steel coarse mesh) window (area approximately 250 cm^2) faced the current. For ease of operation, the cylinder is provided with two side handles and the lower edge is serrated with teeth 1 cm deep. Any Cladophora within the sampler was detached by hand so that it would then be swept by the water current into the collecting bag attached to the cylinder directly opposite the gauze window. This collecting bag (approximately 50 cm in length and constructed of 15 meshes cm^{-1} nylon bolting cloth) is provided with a canvas collar containing a draw cord, by which means it is tied to a flanged collar protruding from the cylinder body around the circular exit port (diameter 13 cm). The net can therefore be

FIGURE 6.2 Diagram of the cylinder sampler used to collect quantitative samples of Cladophora from riffles



detached in order to transfer the sample to a container for transport to the laboratory. Three samples were taken at random from each station, transferred to a single container and subsequently cleaned, rinsed and pressed dry in the laboratory as described above. After drying to constant weight at 105 ^{o}C in preweighed evaporating dishes, the dry weight of the samples could be determined by difference and the results converted to grams dry weight per square metre.

6.2.3 Results and Discussion

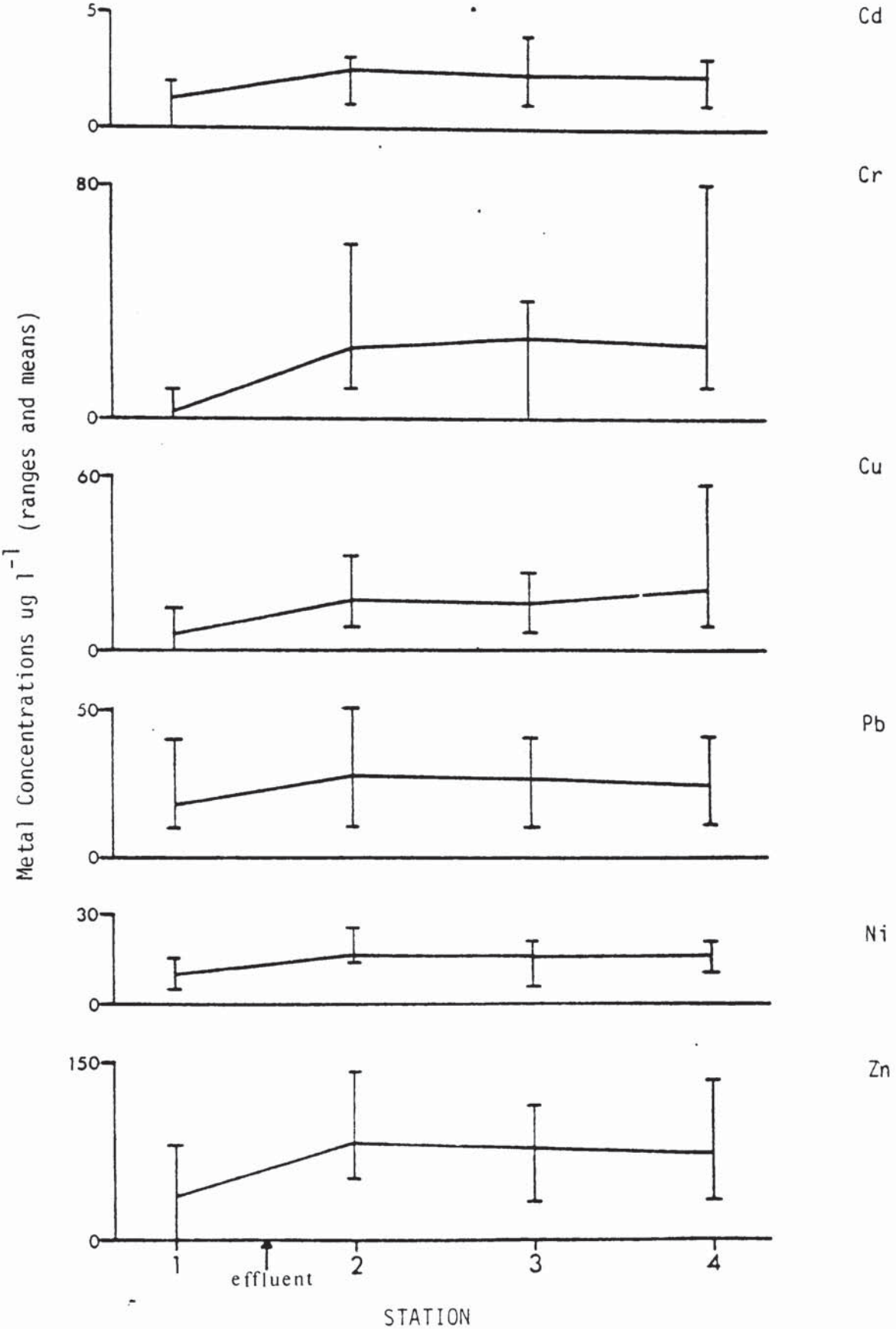
The physico-chemical data for the entire investigation are presented in Appendix 1 (Table A1.13) and a summary of these data in the form of ranges and means appears in Table 6.1. At the beginning of the investigation, current velocities were relatively high at all stations, but earthworking activity by the Water Authority at Station 4 resulted in considerable disturbance to the bed and reduced current velocities at this station from the third sampling date to the end of the study. Throughout this period, samples were taken from apparently undisturbed areas of the river at station 4, but because of the reduced current velocities this station must be considered atypical. Water temperatures increased generally throughout the period of study, but on all sampling dates an increase in temperature was found downstream of the discharge. Increases in suspended solids, chlorides, alkalinity, hardness, BOD, ammonia, nitrates and phosphates also occurred consistently downstream of the discharge, and a clear oxygen sag effect was always apparent. The metals data are plotted in Figure 6.3. Cd was present at low levels and Zn at relatively high levels, but

TABLE 8.1 River Tean *Cladophora* survey: Summary of physico-chemical data

Chemical parameters in mg.ℓ^{-1}.

STATION	1		2		3		4	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Current velocity cm sec^{-1}	61.4- 87.3	72.3	50.0- 72.3	63.9	53.8- 84.1	65.3	7.7- 93.7	39 5
Temperature ^{o}C	5.0- 13:8	9.6	6.6- 14.8	10.6	5.0- 14.7	10.0	5 2- 15.9	10 3
Suspended solids	5.0- 53.5	12.8	11.75-59.5	21 2	7.5-163.0	30.2	5.75-152.0	31.1
Chlorides	22.0- 68.0	37.0	38.0- 92.0	63.0	31.0- 87.0	55.0	28.0- 66.0	50.1
Alkalinity	85.0-155.0	127.6	100.0-185.0	162.2	100.0-185.0	166.7	100.0-193.0	165.3
Total hardness	166.0-250.0	219.0	182.0-276.0	247.8	180.0-296.0	267.3	192.0-296.0	267.3
Ca hardness	130.0-190.0	167.3	138.0-198.0	179.6	140.0-204.0	188.7	148.0-206.0	188.9
Mg hardness	36.0- 60.0	51.7	44.0- 80.0	68.2	40.0- 92.0	78.9	44.0- 90.0	78.4
pH	7.3- 7.6	7.50	7.2- 7.5	7.34	7.2- 7.5	7.37	7.2- 7.6	7.49
Dissolved oxygen	9.2- 12.1	10.74	8.2- 10.1	9.30	8.4- 10.8	9.00	5.2- 11.7	9.70
BOD	1.8- 2.6	2.8	3.3- 7.1	5.0	0.3- 8.7	4.5	3.3- 8.4	5 2
Ammonia	0.1- 0.85	0.44	0.2- 1.45	0.99	0.3- 3.2	1.16	0.2- 1.35	0.85
Nitrates	3.1- 4.4	3.78	4.1- 6.5	5.71	4.0- 8.8	6.53	4.0- 8.5	6.33
Phosphates	0.2- 0.8	0.60	1.8- 3.4	2.53	1.3- 3.6	2.44	1.6- 3.6	2.29
Cadmium	0- 0.002	0.0013	0.001- 0.003	0.0025	0.001- 0.004	0.0024	0.001- 0.003	0.0024
Chromium	0- 0.010	0.0020	0.010- 0.060	0.0250	0- 0.040	0.0280	0.010- 0.080	0.0250
Copper	0- 0.014	0.0058	0.008- 0.032	0.0178	0.006- 0.026	0.0166	0.008- 0.056	0.0206
Lead	0.010- 0.040	0.0180	0.010- 0.050	0.0280	0.010- 0.040	0.0270	0.010- 0.040	0.0250
Nickel	0.005- 0.015	0.0105	0.015- 0.025	0.0165	0.005- 0.020	0.0160	0 010- 0.020	0.0165
Zinc	0- 0.080	0.0380	0.050- 0.140	0.0830	0.030- 0.110	0.0780	0.030- 0.130	0.0710

FIG. 6.3 River Tean *Cladophora* survey:
Metal concentrations ($\mu g\ l^{-1}$) in river water
(ranges and means)



all the metals studied were again present at higher levels downstream of the discharge. This was particularly apparent in the case of Cr.

The Cladophora in the river was identified as C. glomerata using the criteria of Van den Hoek (1963). The biomass data are presented in Table 6.2 and plotted in Figure **6**.4.

There was a steady increase in growth at stations 2, 3 and 4 from the beginning of the investigation, culminating in a large growth peak at station 3 towards the end of May. On subsequent sampling dates, much less Cladophora was found at all stations. The alga was encountered at station 1 on only three occasions, and then only in relatively small quantities. This was consistent with the widely held belief that waters containing relatively low levels of phosphorus support only modest growths of the alga. Reduced current velocities at station 4, as explained above, may have interfered with Cladophora growth, especially towards the end of the investigation when larger growths might have been expected there.

The results of the Cladophora metals analyses (blank-corrected) are presented in Table 6.3. These data appear to be incomplete because sufficient algal material for metal analysis was not always encountered at each station. The figures in brackets are the corresponding concentration factors, calculated as the ratio of the metal content of the Cladophora ($\mu g.g^{-1}$) to the mean metal concentration in the water at the same station ($\mu g\ ml^{-1}$). These factors range from 0.6×10^3 to 11.4×10^3 for the samples and

TABLE 6.2 River Tean Cladophora survey:

Cladophora biomass gm^{-2} dry weight

STATION / DATE	1	2	3	4
1.3.1978	-	-	1.30	5.32
15.3.1978	-	0.51	8.44	9.48
30.3.1978	-	3.03	13.65	14.62
11.4.1978	-	15.64	14.95	31.42
25.4.1978	-	34.56	23.16	14.69
9.5.1978	4.69	35.42	55.01	38.05
24.5.1978	10.25	67.75	130.10	56.45
6.6.1978	0.78	19.78	66.13	0.45
20.6.1978	-	34.78	25.97	-
4.7.1978	-	12.95	21.68	-

Fig. 6.4 River Tean *Cladophora* survey:
Cladophora biomass gm^{-2} dry weight.

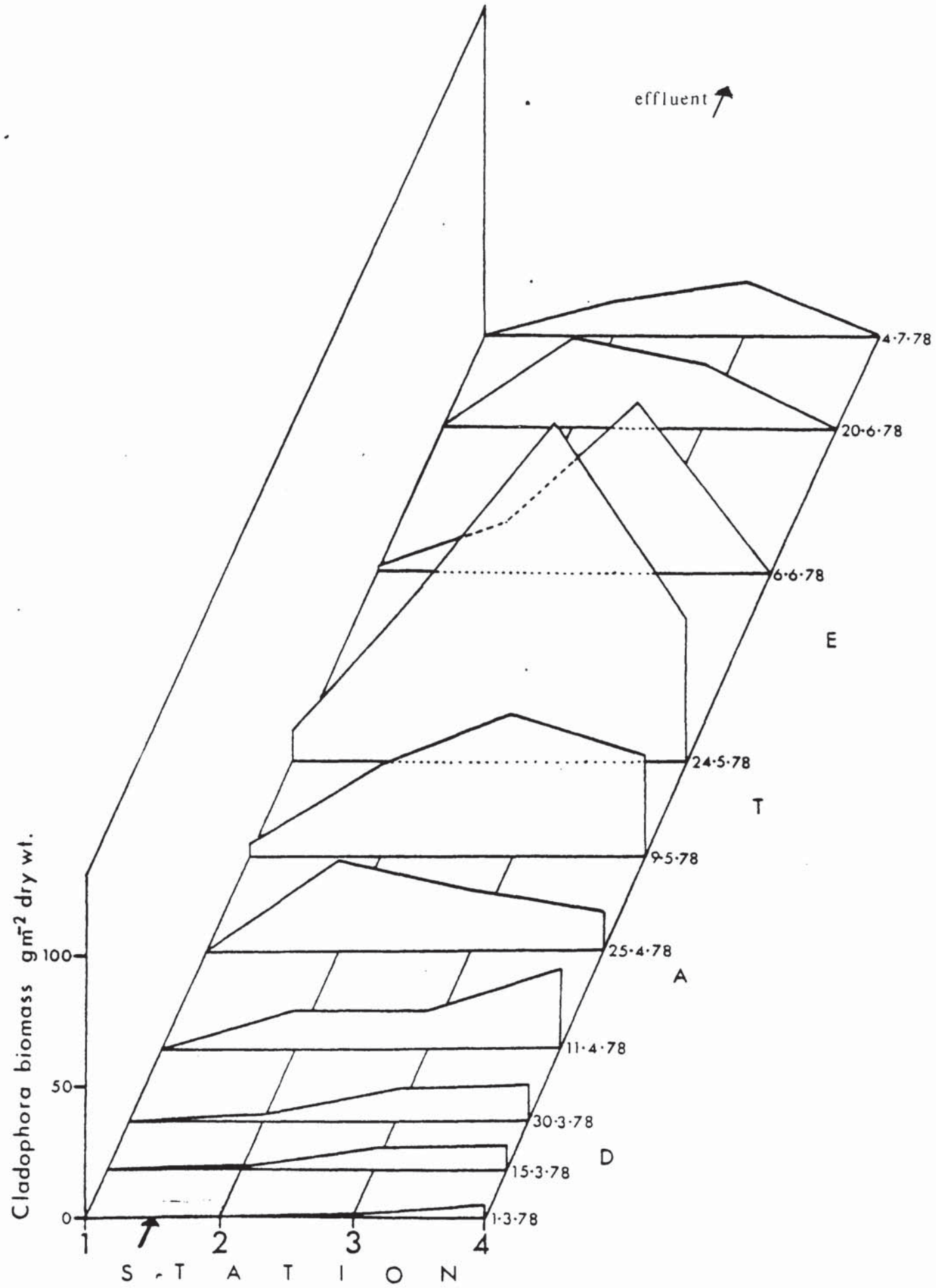


TABLE 6.3: River Tean *Cladophora* survey : Metals data

DATE	Metal Content $\mu g\ g^{-1}$ and (Concentration Factor x 10^{-3})											
	STATION	Cadmium		Chromium		Copper		Lead		Nickel		Zinc	
1.3. 1978	3	8.0	(3.3)	287.0	(10.3)	53.3	(3.2)	120.0	(4.4)	40.0	(2.5)	555.5	(7.1)
	4	3.5	(1.5)	202.5	(8.1)	24.5	(1.2)	90.0	(3.6)	14.0	(0.8)	355.5	(5.0)
15.3.1978	3	11.0	(4.6)	209.0	(7.5)	78.5	(4.7)	117.5	(4.4)	27.5	(1.7)	637.0	(8.2)
	4	5.5	(2.3)	137.0	(5.5)	45.0	(2.2)	85.0	(3.4)	22.5	(1.4)	443.0	(6.2)
30.3.1978	3	5.5	(2.3)	101.0	(3.6)	52.0	(3.1)	72.5	(2.7)	22.5	(1.4)	380.5	(4.9)
	4	6.0	(2.5)	77.5	(3.1)	58.0	(2.8)	65.0	(2.6)	27.5	(1.7)	418.0	(5.9)
11.4.1978	2	6.0	(2.4)	102.5	(4.1)	55.0	(3.1)	77.5	(2.8)	26.0	(1.6)	430.5	(5.2)
	3	5.0	(2.1)	121.0	(4.3)	68.5	(4.1)	75.0	(2.8)	20.0	(1.3)	380.5	(4.9)
	4	7.0	(2.9)	89.0	(3.6)	46.0	(2.2)	62.5	(2.5)	32.5	(2.0)	362.0	(5.1)
25.4.1978	2	6.5	(2.6)	119.0	(4.8)	86.5	(4.9)	97.5	(3.5)	24.0	(1.5)	455.5	(5.5)
	3	5.5	(2.3)	149.5	(5.3)	61.0	(3.7)	82.5	(3.1)	27.5	(1.7)	362.0	(4.6)
	4	5.0	(2.1)	78.5	(3.1)	54.0	(2.6)	47.5	(1.9)	32.5	(2.0)	399.5	(5.6)
9.5.1978	2	6.0	(2.4)	126.5	(5.1)	72.0	(4.0)	100.0	(3.6)	25.0	(1.5)	462.0	(5.6)
	3	5.5	(2.3)	158.0	(5.6)	59.0	(3.6)	95.0	(3.5)	25.0	(1.6)	368.0	(4.7)
	4	6.5	(2.7)	115.0	(4.6)	62.0	(3.0)	80.0	(3.2)	37.5	(2.3)	499.5	(7.0)
24.5.1978	1	2.0	(1.5)	11.0	(5.5)	20.5	(3.5)	22.5	(1.3)	16.0	(1.5)	293.0	(7.7)
	2	7.0	(2.8)	251.0	(10.0)	84.0	(4.7)	150.0	(5.4)	25.0	(1.5)	449.5	(5.4)
	3	8.5	(3.5)	318.5	(11.4)	80.5	(4.8)	112.5	(4.2)	25.0	(1.6)	480.5	(6.2)
	4	6.0	(2.5)	133.0	(5.3)	47.0	(2.3)	42.5	(1.7)	31.0	(1.9)	399.5	(5.6)
6.6.1978	2	10.0	(4.0)	256.0	(10.2)	120.5	(6.8)	212.5	(7.6)	31 0	(1.9)	637.0	(7.7)
	3	5.5	(2.3)	187.5	(6.7)	46.0	(2.8)	92.5	(3.4)	16.0	(1.0)	318.0	(4.1)
20.6.1978	2	7.5	(3.0)	254.0	(10.2)	76.0	(4.3)	97.5	(3.5)	19.0	(1.2)	462.0	(5.6)
	3	6.0	(2.5)	205.5	(7.3)	39.0	(2.3)	52.5	(1.9)	15.0	(0.9)	274.5	(3.5)
4.7.1978	2	13.0	(5.2)	214.0	(8.6)	110.5	(6.2)	157.5	(5.6)	37.5	(2.3)	743.0	(8.9)
	3	3.5	(1.5)	90.0	(3.2)	28.0	(1.7)	40.0	(1.5)	10.0	(0.6)	243.0	(3.1)

elements studied. A comparison of the concentration factors found in this study with those reported by Keeney et al. (1976) for C. glomerata in Lake Ontario is given in Table 6.4.

These workers found higher concentration factors for Cd and Pb but their data for Cu and Zn are comparable or slightly lower. They also quoted concentration factors for Cu reported by other workers of 1.0×10^3 in Lake Erie and 2.5×10^3 in the Spokane River. Whitton (1979) reported a concentration factor over a range of Zn concentrations in water from 0.01 to 0.35 mg l^{-1} of approximately 1.3×10^3. It would appear from these data that the majority of concentration factors fall within the range of 1.0×10^3 to 10×10^3, and rarely exceed 20×10^3.

Graphs to show the detailed spatial and temporal variations in concentration factors for the present study are presented in Figures 6.5 and 6.6. The Zn graphs also incorporate a plot of the appropriate Cladophora biomass data. The data presented in Figure 6.5 for spatial variation in concentration factors on each sampling date are difficult to interpret, owing to their fragmentary nature and the fact that station 4 was suspected to be atypical. At the beginning of the investigation, when Cladophora biomass in the river was low at stations 2 and 3, concentration factors were relatively high, suggesting rapid initial uptake of metals. Moreover, concentration factors were found to be relatively high at station 2 as soon as data became available for this station, and indeed concentration factors remained generally stable for each metal for the first six sampling dates. The only complete set of data, for May 24th, shows more variability; Cd, Cr, Cu and Pb exhibit roughly the

TABLE 6.4 Comparison of concentration factors found in this study with those reported by Keeney *et al.* (1976)

Metal	Concentration Factors ($\times 10^3$)	
	This Study	Keeney *et al.* (1976)
Cd	1.5 - 5.2	18 and 49
Cr	3.1 -11.4	-
Cu	1.2 - 6.2	1.9 and 2.2
Pb	1.3 - 7.6	16 and 20
Ni	0.6 - 2.5	-
Zn	3.1 - 8.9	1.0 and 2.9

Fig. 6.5 River Tean *Cladophora* survey :
Spatial variation in concentration factors.

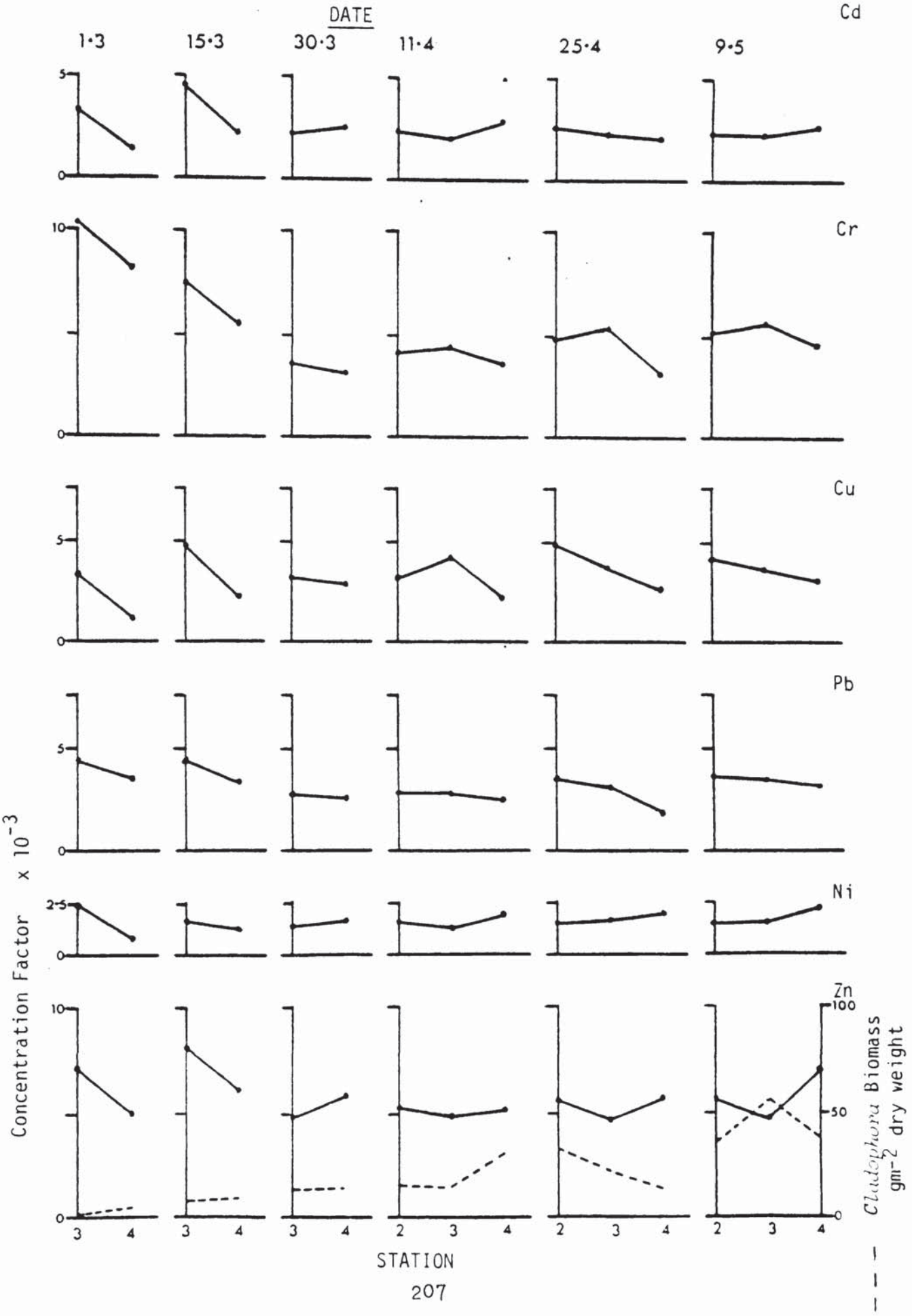
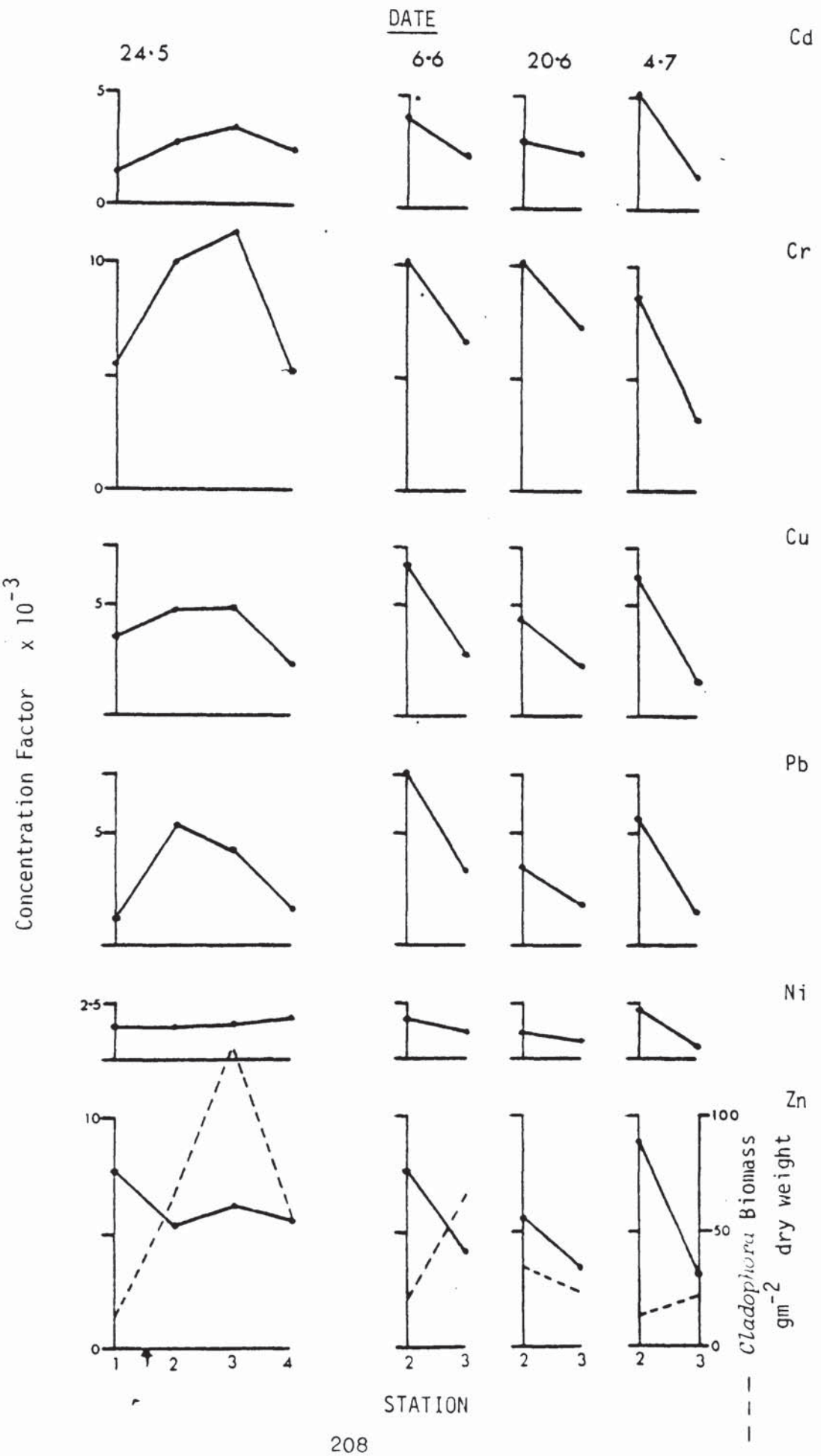


Fig. 6.5 (continued)



same pattern of relatively high concentration factors at stations 2 and 3, corresponding to high Cladophora biomass in the river at these stations. The results for Ni and Zn show relative stability, however. The last three sampling dates are characterised by higher concentration factors at station 2 than at station 3.

The data presented in Figure 6.6 for temporal variation in concentration factors at stations 2, 3 and 4 indicates more clearly the relationship between concentration factors and Cladophora biomass. In each case it is noticeable that high concentration factors occur during periods of rapid growth activity. Although biomass alone is not an index of productivity, it can be assumed that high biomasses tend to follow recent periods of rapid growth. Thus concentration factors were generally high in the period May 9th to June 6th (this is particularly apparent at station 3, where a marked peak in concentration factors for all metals correspond to the massive Cladophora growth peak on May 24th). As mentioned above, it is also apparent that concentration factors were generally high at the beginning of the investigation, when Cladophora biomass was low in the river. It could be that if a small healthy stand of Cladophora is found early in the growing season to contain high levels of accumulated metals, then rapid growth, producing much larger stands, is about to take place.

The data presented here seem consistent with the hypothesis that initial metal uptake in a stand of Cladophora is rapid, but eventually tends to equilibrate to environmental levels. Further substantial uptake will take place if the stand continues rapid, active growth and maintains position. This tendency will be

Fig. 6.6 River Tean *Cladophora* survey : Temporal variation in concentration factors

STATION 2

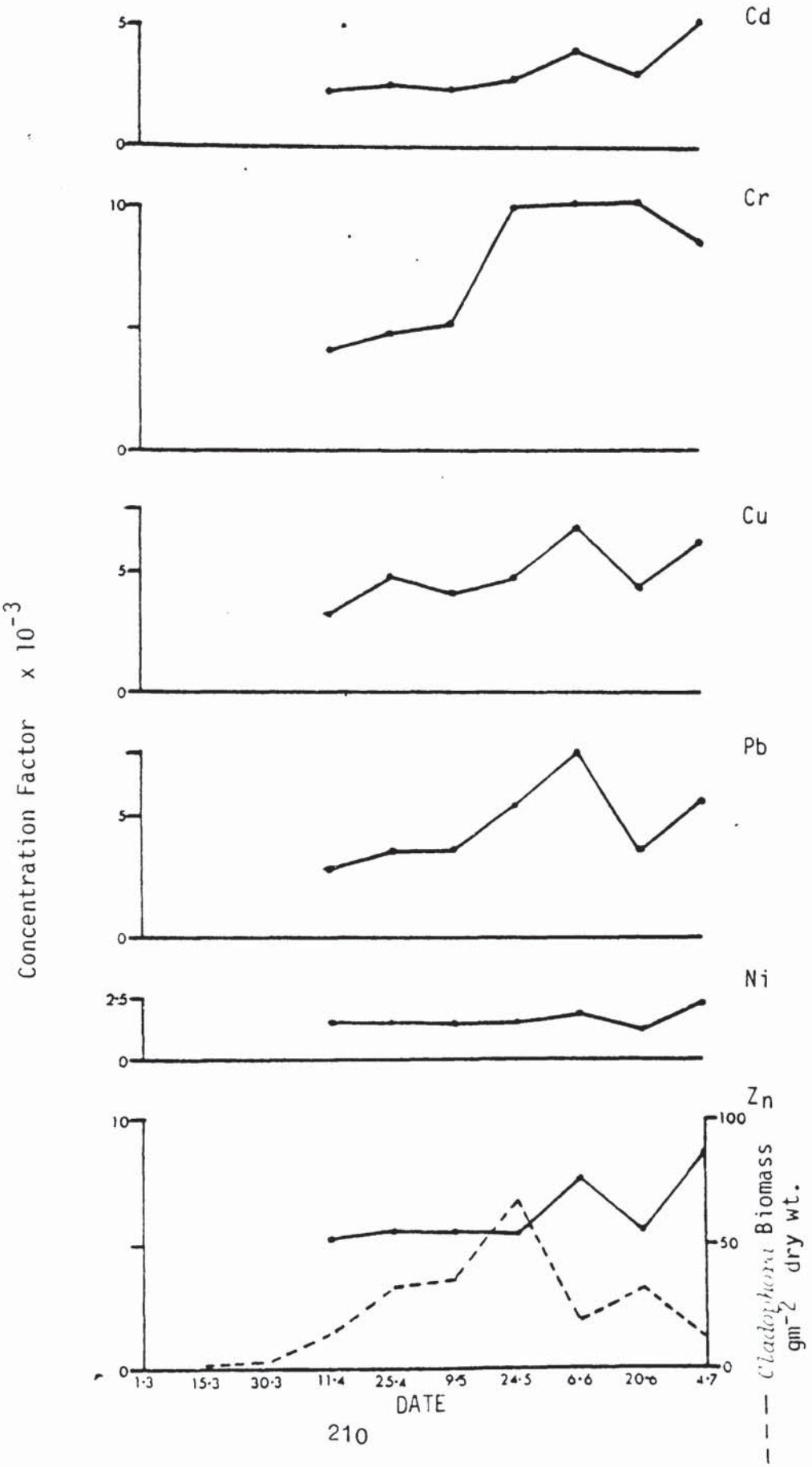


Fig. 6.6 (continued)

STATION 3

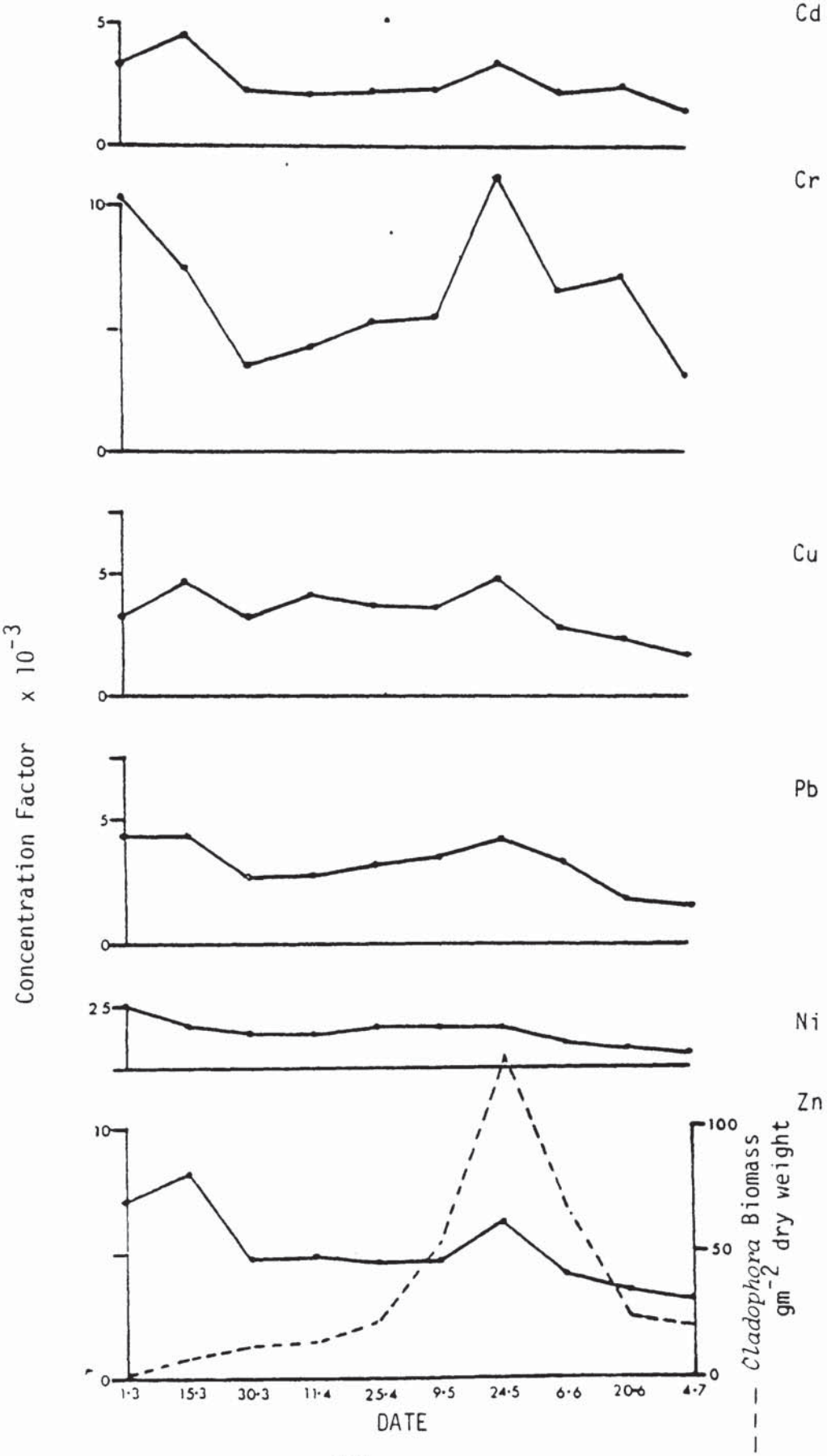
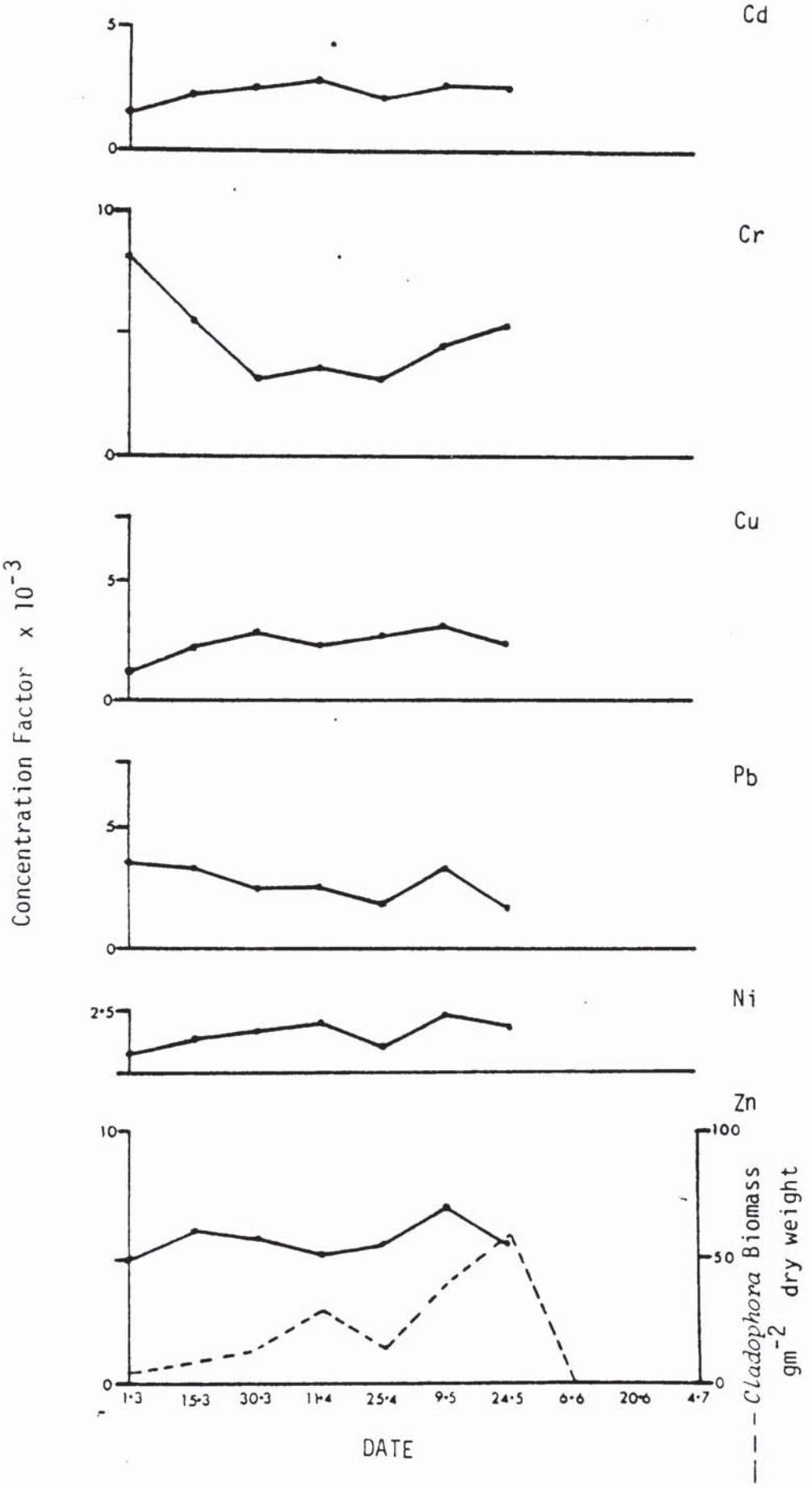


Fig. 6.6 (continued)

STATION 4



counteracted if growth slows or ceases, if a moribund phase is entered or if excessive detachment or loss takes place. Any one stand of Cladophora is subject to all these factors, but their relative importance may vary in space and time, often stochastically. This would lead to some variation in concentration factors in any survey, but this variation may be considered tolerable. Although the digestion procedure requires further refinement, it is simple and suitable at least for comparative purposes. Certainly, Cladophora would appear to exhibit many of the characteristics mentioned by Phillips (1977) as desirable for this type of work (see Section 3.2.2.2) and analysis of Cladophora would in most cases provide information on metal pollution which could then be investigated further using more sophisticated techniques.

6.3 Studies on the use of laboratory flask cultures of Cladophora to assay the growth promoting properties of river waters

6.3.1 Objectives

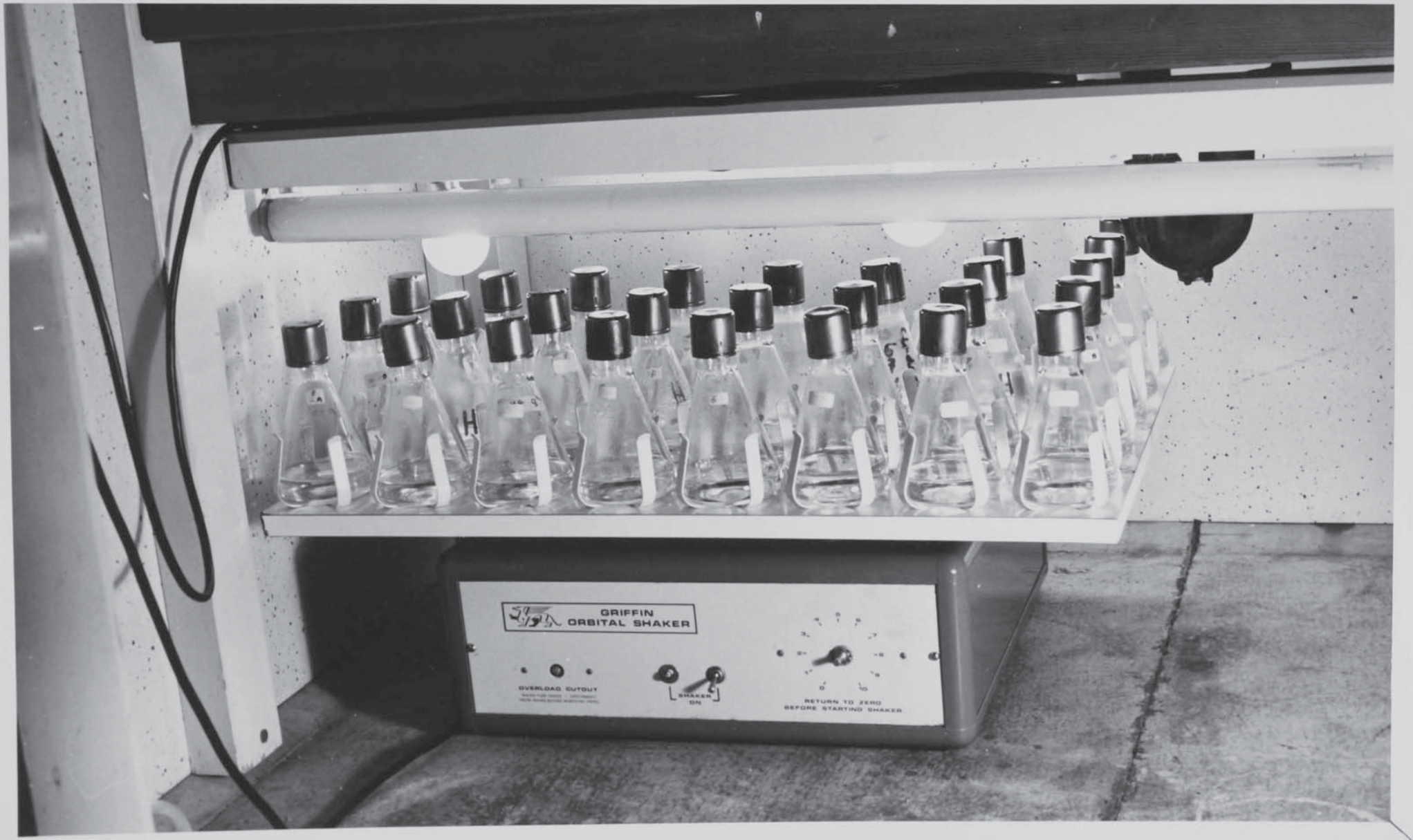
It was reasoned that if river waters known to be potentially capable of supporting growths of Cladophora in the field could also be induced to elicit an analogous effect under laboratory conditions, this might form the basis of a bioassay procedure to assess the potential of river waters in general to support growths of this alga. Such a predictive tool would be of value in the making of certain water management policy decisions. The objectives of this investigation were to make preliminary attempts

to develop such a technique. It was decided to use the Tean as a test river, since detailed surveillance data were available from the survey work described in Section 6.2; the two investigations were in fact carried out concurrently.

6.3.2 Methods

The methods employed were based on those described by Whitton (1967) and Pitcairn and Hawkes (1973). Experiments were carried out in 250 ml conical flasks, each containing 100 ml of the water under test, and closed with an Oxoid aluminium cap. Cladophora collected from river Tean station 3 (Figure 6.1) immediately before the start of each experiment was washed and examined for epiphytes, and clean, well branched pieces 2 cm in length were detached with fine scissors and used as inocula, one such piece being introduced into each flask. In each experiment, five replicate flasks were prepared from each water sample. The flasks were transferred to an orbital shaker (Figure 6.7) in a controlled temperature cabinet maintained at 15 ^{o}C. To mark the start of the experiment, the shaker was set in motion at 100 cycles per minute. The entire apparatus was illuminated from above for 18 hours per day (0600h to 2400h), illumination being provided by two 30W white fluorescent tubes and two 60W tungsten filament bulbs suspended some 25 cm above the shaker table. These maintained a mean illuminance at the level of the culture of 4500 lux, but tended to raise the temperature of the cultures to 18-20 ^{o}C during the photoperiod. Growth was measured as mg total dry weight after 10 days under these conditions. At the end of each experiment, the Cladophora

FIGURE 6.7 (overleaf)
Cladophora Flask Experiments: The Experimental Apparatus


GRIFFIN
ORBITAL SHAKER
OVERLOAD CUTOUT
SHAKER
ON
RETURN TO ZERO
BEFORE STARTING SHAKER

present in each flask was recovered by retention in a 500 um sieve and dried to constant weight on pre-weighed Whatman GF/C 7.0 cm filter papers; the total dry weight could then be determined by difference. The initial dry weights of the inocula had of necessity to be ignored, but tests indicated these to be reasonably constant within the range 0.5 - 1.0 mg in all experiments.

A total of six experiments was carried out, the water and Cladophora samples for each being collected separately. In experiment 1, Cladophora was grown in water taken from each of the four Tean stations (Figure 6.1). Experiments 2 and 3 were essentially repeats of experiment 1, but in experiment 3 all the water samples were first filtered through Whatman GF/C papers. These have been shown by Melbourne (1964) to retain the majority of solids particles exceeding 0.5 μm diameter. In experiment 4, water samples again collected from each of the four Tean stations were used to prepare two series of replicated flasks: an untreated control series (as in experiments 1 and 2) and a parallel experimental series in which water from the same original samples was filtered as above. Experiment 5 was similar in design, but in this case the experimental treatment was to renew the water in the flasks daily from the same original samples (stored for the duration of the experiment in a refrigerator, but equilibrated to cabinet temperature before renewal took place). Finally in experiment 6, Cladophora was grown in mixtures containing Tean station 1 water and Blithe Valley Water Reclamation Works final effluent, in the following proportions: 100:0, 95:5; 90:10, 85:15; 75:25, 50:50, 25:75 and 0:100.

6.3.3 Results and Discussion

The complete experimental results, including the ammonia, nitrate and phosphate levels in the test waters at the beginning of each experiment (except experiment 6) are presented in Table 6.5. Histograms of the Cladophora biomass data (means only) are presented in Figure 6.8. These data were also subjected to statistical analysis using a standard one-way analysis of variance followed by the Duncan (1955) multiple range test, to seek significant differences between individual means. The findings of these tests are summarised in Table 6.6.

The chemical data indicate increased levels of nitrogen and phosphorus in the samples taken from stations 2, 3 and 4, downstream of the Checkley discharge. In general, ammonia levels remained relatively low at all stations, whilst nitrate levels were relatively high, showing marked increases below the discharge. In all experiments, phosphorus levels in station 1 water were below 1 mg P l^{-1}, but again substantial phosphorus increases occurred in samples taken downstream of the discharge. Pitcairn and Hawkes (1973) made a number of observations on the growth of Cladophora in flask culture that are of interest here. They found that whilst significant reduction in growth occurred below 1 mg P l^{-1}, no significant increase took place above this level. More interestingly, growth of Cladophora in waters upstream of sewage discharges could be increased to downstream levels simply by the addition of phosphorus. An interaction was also found between nitrogen and phosphorus; the highest level of nitrate (7.7 mg N l^{-1}) enhanced growth at the lowest phosphorus level

TABLE 6.5 *Cladophora* Flask Experiments: Results

EXPERIMENT 1

Treatment		None			
Station		1	2	3	4
NH_4^+ - N mg l^{-1}		0.2	1.6	0.8	0.6
NO_3 - N mg l^{-1}		3.8	6.6	4.9	5.1
PO_4 - P mg l^{-1}		0.2	2.7	1.3	1.3
mg. dry wt. 10d	Replicates	16.0	17.6	2.8	11.3
		11.2	13.0	24.5	15.3
		32.6	6.4	3.1	18.6
		10.7	26.9	8.7	15.9
		16.7	6.3	14.9	18.8
	Mean	17.44	14.04	10.80	15.98

EXPERIMENT 2

Treatment		None			
Station		1	2	3	4
NH_4^+ - N mg l^{-1}		0.2	0.7	0.7	0.4
NO_3 - N mg l^{-1}		3.7	6.0	7.4	7.3
PO_4 - P mg l^{-1}		0.7	2.6	2.4	2.2
mg. dry wt. 10d	Replicates	14.4	4.2	3.8	2.7
		8.6	8.1	1.5	2.5
		12.7	4.8	7.6	7.4
		6.4	6.1	7.0	3.1
		15.5	1.6	3.2	3.4
	Mean	11.52	4.96	4.62	3.82

EXPERIMENT 3

Treatment		All water samples filtered			
Station		1	2	3	4
NH_4^+ - N mg l^{-1}		0.3	0.3	0.3	0.2
NO_3 - N mg l^{-1}		3.6	6.5	8.3	8.5
PO_4 - P mg l^{-1}		0.7	2.4	3.0	3.0
mg. dry wt. 10d	Replicates	16.8	All inocula died; little or no growth.		
		14.9			
		15.9			
		18.8			
		16.9			
	Mean	16.66			

TABLE 6.5. (continued)

EXPERIMENT 4

Treatment		(a) None (control)				(b) Water filtered			
Station		1	2	3	4	1	2	3	4
NH_4^+ - N mg l^{-1}		0.2	0.5	0.2	0.3				
NO_3 - N mg l^{-1}		3.2	6.9	7.4	8.3	As for Control			
PO_4 - P mg l^{-1}		0.9	2.5	3.5	4.0				
mg dry wt 10d	Replicates	24.3	10.7	8.3	14.8	24.4	15.0	11.4	12.3
		14.7	5.9	13.1	9.2	17.0	11.3	19.9	11.7
		22.2	12.6	11.0	9.7	33.0	12.6	22.4	12.6
		14.9	16.4	16.1	10.3	22.5	13.7	20.5	15.7
		19.7	9.8	12.5	17.2	25.7	11.3	9.3	13.0
	Mean	19.16	11.08	12.20	12.24	24.52	12.78	16.70	13.06

EXPERIMENT 5

Treatment		(a) None (control)				(b) Water removed daily			
Station		1	2	3	4	1	2	3	4
NH_4^+ - N mg l^{-1}		0.0	0.2	0.2	0.2				
NO_3 - N mg l^{-1}		3.1	5.4	8.1	8.0	As for Control			
PO_4 - P mg l^{-1}		0.9	1.9	3.3	3.6				
mg dry wt. 10d	Replicates	21.7	21.6	20.1	14.9	7.3	22.0	17.5	11.7
		14.8	21.0	14.2	14.0	2.5	34.2	13.1	13.5
		12.9	13.9	10.4	21.8	4.7	19.8	20.5	13.5
		11.2	23.1	15.3	6.9	7.4	12.5	15.9	13.9
		15.6	19.0	15.1	8.6	2.1	11.5	21.8	20.7
	Mean	15.24	19.72	15.02	13.24	4.8	20.00	17.76	14.66

EXPERIMENT 6

Treatment		Different proportions Station 1 water: sewage effluent							
% Effluent		0	5	10	15	25	50	75	100
NH_4^+ - N mg l^{-1}		-	-	-	-	-	-	-	-
NO_3 - N mg l^{-1}		-	-	-	-	-	-	-	-
PO_4 - P mg l^{-1}		-	-	-	-	-	-	-	-
mg dry wt. 10d	Replicates	15.8	15.5	13.1	8.7	9.1	3.3	7.1	6.3
		11.2	28.7	17.6	1.9	2.0	4.2	5.0	3.3
		16.5	18.8	9.1	8.6	8.3	2.1	4.8	2.0
		17.1	6.0	14.7	9.3	6.7	3.1	3.6	3.8
		18.3	15.0	18.6	8.1	6.0	3.2	4.4	6.2
	Mean	15.78	16.8	14.62	7.32	6.42	3.18	4.98	4.32

Fig. 6.8 *Cladophora* Flask Experiments: Results

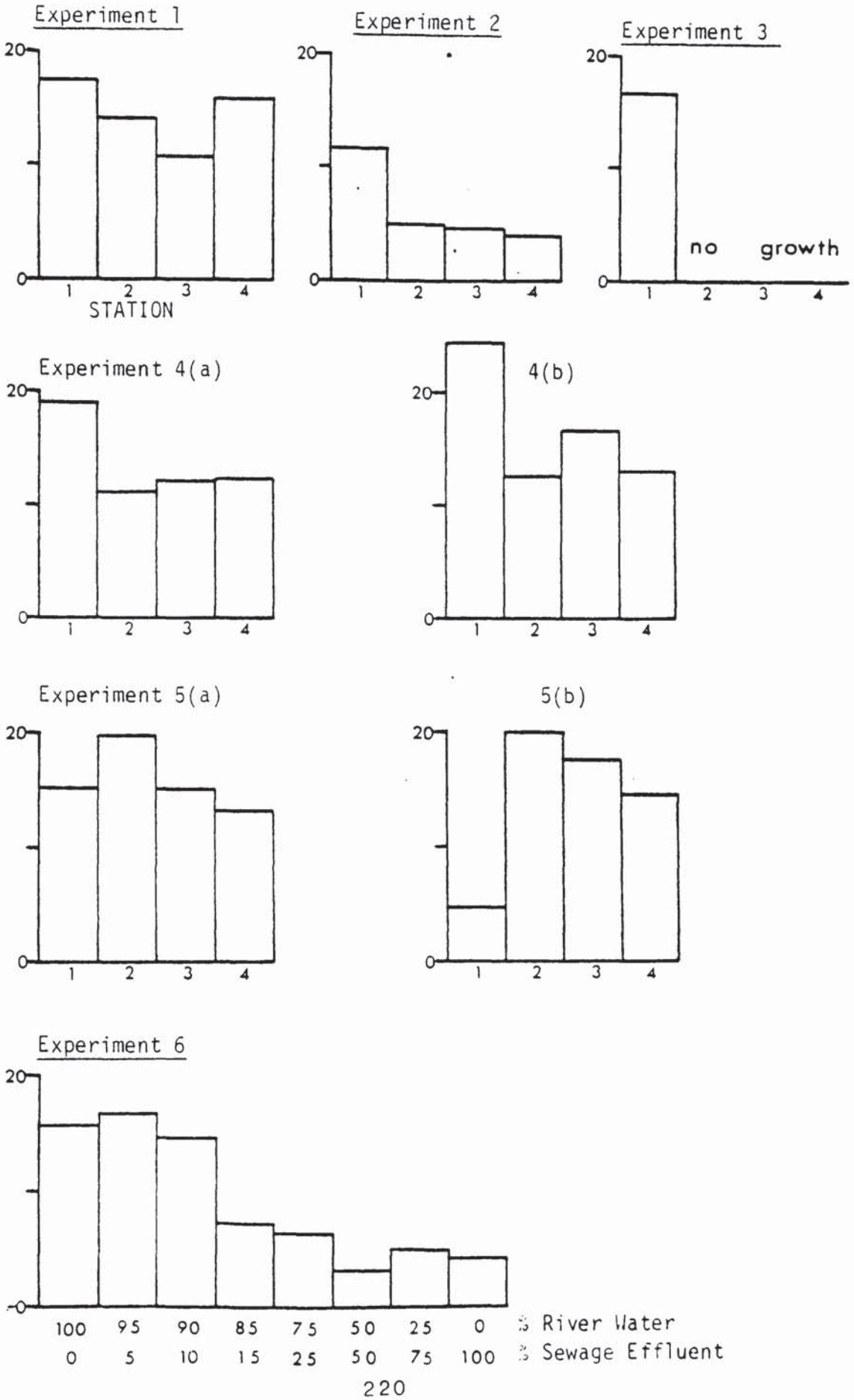


TABLE 6.6 STATISTICAL ANALYSIS OF THE *Cladophora* BIOMASS DATA (mg dry wt. 10d) USING THE DUNCAN (1955) MULTIPLE RANGE TEST

Expt.									P
1	Stations	3	2	4	1				
	Means	10.80	14.04	15.98	17.44				
		———							5%
		———	———	———					1%
2	Stations	4	3	2	1				
	Means	3.82	4.62	4.96	11.52				
		———	———						5%
		———	———	———					1%
3	Stations	4	3	2	1				
	Means	0	0	0	16.66				
		———	———						5%
		———	———	———					1%
4(a)	Stations	2	3	4	1				
	Means	11.08	12.20	12.24	19.16				
		———	———						5%
		———	———	———	———				1%
4(b)	Stations	2	4	3	1				
	Means	12.78	13.06	16.70	24.52				
		———	———						5%
		———	———	———	———				1%
5(a)	Stations	4	3	1	2				
	Means	13.24	15.02	15.24	19.72				
		———	———	———					5%
		———	———	———	———				1%
5(b)	Stations	1	4	3	2				
	Means	4.8	14.66	17.76	20.00				
		———	———	———	———				5%
		———	———	———	———				1%
6	% Effluent	50	100	75	25	15	10	0	5	
	Means	3.18	4.32	4.98	6.42	7.32	14.62	15.78	16.80	
		———	———	———	———	———	———	———	———	5%
		———	———	———	———	———	———	———	———	1%

Note: Any two means not underscored by the same line are significantly different at the level indicated, and any two underscored by the same line are not significantly different.

(0.5 mg P l^{-1}) but at higher levels of phosphorus, growth was reduced.

Returning to the present work, in experiments 1, 2 and 3, Cladophora growth in culture did not reflect natural Cladophora growth in the river, in that growth in culture was in each experiment greatest in station 1 water. Statistical analysis indicated no significant differences between the four stations in experiment 1, but in experiments 2 and 3, growth in water taken from stations 2, 3 and 4 was significantly lower than in station 1 water. This effect was particularly apparent in experiment 3 (filtered water), with no growth at all occurring in the downstream waters. Experiment 4 again indicated relatively higher growth in station 1 water (significant at the 5% level) but standard t-tests indicated no significant differences between corresponding stations in experiments 4(a) and 4(b), i.e. between unfiltered and filtered water samples. This result therefore contrasted sharply with experiment 3 mentioned above. In experiment 5(a), growth in station 1 water was for the first time found to be less than in station 2 water, although the Duncan test showed no significant difference between the four means at the 1% level. However, daily renewal of the test waters as carried out in experiment 5(b) resulted in greatly reduced growth in station 1 water but apparently had little effect on growth in the downstream waters. Standard t-tests confirmed the only significant difference between experiments 5(a) and 5(b) was between the station 1 means ($t = 4.94$). Field conditions were thus simulated most convincingly in experiment 5(b), simply by daily renewal of the test waters. This was presumably because daily renewal approximated more closely to the lotic situation

than the ten day batch culture technique employed in experiments 1 to 4. Nevertheless, it is difficult to explain the apparent suppression or inhibition of growth that occurred in experiment 5(b) in station 1 water; it would be expected that daily renewal of water would encourage growth by replacing depleted growth factors and removing any inhibitory extracellular metabolites (Section 3.2.1). It seems possible that continued growth in station 1 water in experiment 5(a) resulted from the accumulation of some growth promoting factor not initially present in the water, but derived directly or indirectly (e.g. by interaction with some other organism) from the Cladophora inocula themselves. This positive feedback effect would be dampened by daily renewal of the medium, i.e. by frequent removal of this factor. Further, this effect was not apparent in the downstream waters, possibly because some other growth factor, derived externally from the sewage works effluent, was already present in these waters. This would explain why daily renewal of the downstream waters had little or no effect on Cladophora growth.

In experiment 6, an attempt was made to assay different mixtures of station 1 water and sewage works effluent. The value of this experiment was limited by the fact that the ten day batch culture technique was again used, and no chemical data were recorded. A marked discontinuity in growth was apparent between 10 and 15% effluent, with growth significantly reduced at the higher concentrations of effluent. The factors involved in this effect, if known, might be of practical value in river management.

The flask culture technique described here is simple and potentially useful as a research or management tool. Some of the results were difficult to interpret, however, and further work would be necessary to establish more clearly the capabilities and limitations of the procedure, and possibly to refine it. One problem not discussed here, but suggested by some of the results, is possible variation in the physiological condition of the inocula. Moore (1975) found that the protein, carbohydrate, lipid, cellulose and ash content of C. glomerata varied inconsistently in time, probably in response to changing environmental conditions. It might be inferred from this that Cladophora samples collected separately in time from one locality might be in different physiological states, and might respond differently in culture. In any one experiment, therefore, good replication of inocula should be obtained if comparisons are to be made between different waters, but it may not be valid to compare the results of different experiments directly. A further complication is that the test waters are themselves subject to sampling error (in any one experiment, the water samples could be atypical), and for these reasons it would be desirable to carry out several replicate experiments to determine the extent of variation between them.

7. GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

In retrospect, the initial objectives of the research programme (Section 2) seem remarkably ambitious, and it must be suggested that many of the weaknesses of the work itself stem directly from the contractual obligation to adhere to them. On the other hand, in at least attempting to achieve these objectives, it was found necessary to adopt a very broad and practical approach, and this in turn has perhaps enabled a reasonably balanced and realistic set of conclusions and recommendations to be made.

Any biological surveillance programme will involve three basic stages - sample collection, sample analysis, and data analysis. The literature reviews (Section 3), together with the findings of the research programme itself (Sections 4, 5 and 6), suggest that a number of serious practical and ecological problems are likely to be encountered at each of these stages, and these must be considered carefully before embarking on any surveillance exercise involving the river benthic algae.

Sample collection and sample analysis are essentially practical problems. Natural substrata should be sampled directly wherever possible, but quantitative work is usually too difficult and time-consuming for routine purposes, and the variability of natural substratum types, and of the organisms themselves, tends to preclude the development of a single standard approach. Qualitative work is more readily carried out, but will convey no information on the quantitative importance of the different taxa present. For routine purposes, therefore, it would seem

justifiable to adopt some essentially semi-quantitative approach, although this compromise is open to criticism, mainly on grounds of subjectivity. For this reason, it would be desirable to develop a generally accepted method for this type of work.

In many situations, particularly in deeper waters, the direct sampling of natural substrata by any method is likely to be difficult and unproductive. Artificial substrata seem to be the only practical means of sample collection in these situations, and would further appear to offer a standard quantitative approach to the general problems of sample collection. In the present investigation, however, the performance of artificial substrata in rivers was found to be disappointing: many were lost or were not adequately colonized, and again, reliable quantitative work would probably be too difficult and time-consuming for routine purposes, owing to the high degree of replication required at each site.

The problems of taxonomy and identification should also be mentioned at this point. The river benthic algae are a difficult group in these respects and if they are to be considered seriously by the Water Authorities for water quality surveillance purposes, they require the specific attention of appropriately qualified biologists.

It must be admitted that the river benthic algae have in general failed to achieve the acceptance and popularity of other groups, particularly the benthic macroinvertebrates, for purposes of water quality surveillance. The problems associated with sample collection and sample analysis have doubtless contributed to this

situation, but it would also seem that algal data are more difficult to interpret, and ultimately less informative than invertebrate data, and most attempts at data simplification have consequently been less successful.

The key to this problem may lie in the ecology of the organisms and assemblages themselves. Mention has already been made of the fact that developmental phenomena such as succession and climax conditions are difficult to recognize in these assemblages, and on further consideration, it would appear that many of their structural and functional attributes, as discussed by Odum (1971, Chapter 9) are in fact characteristic of a relatively low level of ecological development. This could explain why there seem to be so few reliable indicator taxa amongst the algae, and why community structure data are so often difficult to interpret. At the organism level, these assemblages consist primarily of small forms with relatively broad niche specialization. This is important in relation to indicator value; as Odum (1971) points out, the turnover rate of small organisms may be so great that the particular species present at any one moment may not be very instructive as an ecological indicator, and of course, broad niche specialization tends to result in correspondingly low indicator value. At the community level, pattern diversity tends to be poorly organized, and stability (resistance to external perturbations) tends also to be poor. River benthic algal assemblages are usually characterized by a relatively high degree of spatial and temporal heterogeneity, and marked changes seem to occur rapidly, and often stochastically, in response to changing environmental conditions. Physical factors such as current and

substratum seem to exert a particularly profound effect in this respect.

The general conclusion is that these assemblages tend to have a relatively low information content, or as Hellawell (1978) phrased it, at present we can only detect the louder 'signals' amidst a great deal of 'noise'. In general, only extremes of water quality are likely to be reliably reflected by these assemblages, and the most useful indicator taxa are large conspicuous forms such as sewage fungus, Stigeoclonium and Cladophora, which seem to grow abundantly only under relatively well-defined environmental conditions.

Broadly similar arguments can probably be applied to the assemblages growing on artificial substrata. In the present work, artificial surfaces suspended in deep waters tended to attract a relatively small range of ubiquitous planktonic diatoms, probably derived from the bed in shallower reaches, but not representing an ecological unit of any great value for water quality surveillance purposes.

The usefulness of the river benthic algae for these purposes must be assessed against this practical and ecological background. As a general rule, the time and effort invested in any surveillance programme should be governed by the probable value of the results in relation to the chosen objectives. Thus, for a large-scale survey involving relatively few samples from a large number of different rivers, it would not seem justifiable to attempt to generate detailed quantitative data. The results, like those of many of the river surveys carried out in the present work, would probably

be too fragmentary for rigorous analysis or ecologically valid interpretation. In such a survey, it would probably be more profitable to concentrate on the natural occurrence and abundance of conspicuous macroscopic growths, particularly of sewage fungus, Stigeoclonium and Cladophora, the last named alga being of interest as a nuisance organism as well as a probable indicator of eutrophic conditions.

At the more local level, for example in the investigation of a single river or discharge, a greater investment of time and effort can justifiably be made. Thus, it may be decided to increase the number of sites sampled (as in the Churnet survey), or to increase the frequency of sampling or the refinement of the procedures used. It may indeed be possible to develop approaches to sampling and data analysis specifically adapted to the system or problem under consideration. In this context, some of the data analysis methods already developed, such as the Saprobien System and the Palmer Index, should be considered further.

It seems reasonable to suggest that the algae are most useful for relatively specific, rather than general surveillance purposes, and in this respect, the use of particular taxa for particular purposes is worthy of consideration. The studies carried out on Cladophora as a bioaccumulation indicator and a bioassay organism suggest some of the possibilities to be exploited.

Finally, it can be said that more work is desirable on

virtually every aspect of the use of the river benthic algae for water quality surveillance purposes, both at the research level, and at the more practical level relevant to the Water Authorities. Only then will it be possible to make sensible use of this particular aspect of applied hydrobiology.

APPENDIX 1 PHYSICO-CHEMICAL DATA

All units mg l^{-1} where appropriate and unless otherwise stated

TABLE A1.1

RIVER WEAVER PHYSICO-CHEMICAL DATA 1977

DATE	Temperature °C				Suspended solids mg.l^{-1}.				Dissolved Oxygen mg.l^{-1}.				Dissolved Oxygen % Saturation			
SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
26. 4.77	4.2	4.4	5.5	5.9	9	11	27	16	7.6	9.6	6.9	7.8	60	77	57	65
24. 5.77	12.4	13.9	13.6	14.4	5	12	14	11	8.65	10.9	7.1	7.4	84	108	71	75
21. 6.77	11.4	12.9	12.9	13.4	8	16	16	11	8.3	10.5	7.4	7.6	78	102	72	75
19. 7.77	14.0	15.5	15.5	16.0	0	2	5	3	7.0	9.4	6.7	4.4	70	97	80	46
16. 8.77	15.5	16.9	16.7	16.8	6	7	5	3	6.1	8.0	4.9	3.2	63	85	52	34
15. 9.77					2	2	5	6	9.7	11.4	4.7	3.3				
11.10.77	8.8	10.2	9.8	10.0	6	79	11	12	8.8	9.9	7.5	5.5	79	91	69	50
11.11.77	10.5	10.9	10.9	10.9	0	4	6	5	7.7	9.3	7.2	7.4	72	87	68	69
6.12.77	3.5	3.3	3.8	4.0	7	9	10	18	11.2	13.0	10.3	0.2	88	100	81	81

TABLE A1.1 (cont.) RIVER WEAVER PHYSICO-CHEMICAL DATA

DATE	Chloride mg l^{-1}.				Alkalinity mg.l^{-1}.				Ammonia N mg.l^{-1}.				Nitrates N mg.l^{-1}.			
SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
26. 4.77	62	107	100	102	152	140	160	150	0.5	0.85	6.7	4.15	7.15	8.6	6.7	7.85
24. 5.77	69	109	117	117	170	155	170	160	0.65	0.9	1.9	2.25	9.1	14.4	12.2	11.8
21. 6.77	62	119	119	114	167.5	155	167.5	160	1.0	1.1	2.5	2.1	6.35	9.35	7.4	7.15
19. 7.77	96	158	152	149	195	167.5	182.5	162.5	3.2	1.15	4.85	4.5	6.3	8.6	7.3	8.4
16. 8.77	90	161	161	156	170	170	170	147.5	0.8	1.5	2.4	1.8	5.7	6.5	5.35	6.0
15. 9.77	88	165	150	151	50	160	175	162.5	1.1	1.15	4.4	2.1	5.2	8.1	6.4	7.7
11.10.77	103	173	152	145	190	175	172.5	157.5	0.9	0.8	1.9	4.0	6.8	8.6	7.4	7.5
11.11.77	80	143	133	129	172.5	162.5	157.5	147.5	3.0	2.25	3.35	3.15				
6.12.77	79	148	135	131	182.5	167.5	160	155	1.75	1.75	5.25	4.9				

TABLE A1.1 (cont.)

RIVER WEAVER PHYSICO-CHEMICAL DATA 1977

DATE	Phosphates mg.l-1.				Total Hardness mg.l-1.				Calcium Hardness mg.l-1.				Magnesium Hardness mg. l-1			
SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
26. 4.77	0.75	1.75	2.25	1.55	392	310	334	324	254	210	218	216	38	100	116	108
24. 5.77	0.35	1.2	1.0	1.15	400	360	370	354	274	238	252	236	126	122	118	118
21. 6.77	0.65	1.35	1.3	1.3	380	338	362	358	274	244	256	244	106	94	106	114
19. 7.77	0.75	1.35	1.9	1.7	456	398	370	357	332	264	250	276	124	134	120	81
16. 8.77	0.7	1.2	1.7	1.5	422	376	352	328	290	154	134	126	132	222	218	202
15. 9.77	0.5	1.3	1.6	1.4	464	370	336	328	264	250	230	222	200	120	106	106
11.10.77	Neg.	1.5	1.3	1.0	472	380	374	342	324	262	234	222	148	118	140	120
11.11.77	0.85	1.15	1.1	1.1	444	378	356	354	298	262	246	236	146	116	110	118
6.12.77	0.5	1.0	1.3	1.35	442	398	388	358	314	266	256	248	128	132	132	110

TABLE A1.1 (cont.)

RIVER WEAVER WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	WEAVER 1		WEAVER 2		WEAVER 3	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	8.6	1.0- 14.5	9.6	1.5- 17.0	10.0	3.0- 17.0
pH	7.7	7.3- 8.2	7.8	7.6- 8.3	7.6	7.3- 7.8
Susp. Solids	14	5 - 38	19	3 - 61	21	2 -103
D.O. Conc$^{n.}$	9.6	7.5- 12.0	10.3	8.3- 12.3	7.8	4.1- 11.2
D.O. % Sat$^{n.}$	81	71 - 92	90	82 -105	66	42 - 87
BOD_5	3.8	1.9- 6.5	4.9	2.3- 12.0	7.7	2.9- 24.0
BOD_5 + ATU						
Chloride	43	28 - 60	109	38 -180	105	48 -154
Alkalinity	200	60 -260	201	130 -240	202	135 -240
Total Hdns.	227	150 -300				
NH_3 -N	0.6	$<$0.1- 2.1	0.7	0.1- 2.7	2.7	1.1- 4.8
NO_3- N	7.4	4.5 14.0	8.7	6.5- 14.5	7.6	5.4- 15.0
Orthophosphate	0.4	0.1- 0.7	0.7	0.25- 1.5	0.9	0.3- 1.7

TABLE A.1.2

RIVER TRENT PHYSICO-CHEMICAL DATA 1977

DATE / SITE	Temperature °C		Suspended Solids mg.l^{-1}		Dissolved Oxygen mg.l^{-1}		Dissolved Oxygen % Saturation	
	1	2	1	2	1	2	1	2
2. 5.77		11.2		21		7.7		72
30. 5.77	13.9	14.0	12	19	10.9	7.4	108	80
27. 6.77	15.0	10.4	5	13	11.2	7.3	114	68
26. 7.77	15.4	15.8	22	15	8.9	6.3	92	65
22. 8.77	16.2	15.6	10	25	9.0	6.3	94	65
20. 9.77			14	10	10.3	7.1		
17.10.77	11.0	12.0	1	18	9.1	6.2	85	60
15.11.77	7.0		19		10.3		88	
13.12.77	7.5	8.0	27	52	10.2	9.1	88	80

DATE / SITE	Chloride mg.l^{-1}		Alkalinity mg.l^{-1}		Ammonia N mg.l^{-1}		Nitrate N mg.l^{-1}	
	1	2	1	2	1	2	1	2
2. 5.77		99		110.0		1.75		15.0
30. 5.77	140	133	155.0	135.0	1.4	2.0	6.7	12.8
27. 6.77	176	125	152.5	125.0	0.85	2.0	9.35	13.4
26. 7.77	164	137	152.5	135.0	1.65	3.25	10.6	26.8
22. 8.77	176	110	142.5	102.5	5.1	7.0	7.6	10.5
20. 9.77	179	137	157.5	137.5	1.1	4.2	7.5	11.75
17.10.77	177	142	150.0	142.5	0.65	1.0	9.0	12.4
15.11.77	123		122.5		1.0		8.5	
13.12.77	113	73	115.0	90.0	1.75	2.15	9.0	10.2

DATE / SITE	Phosphate mg.l^{-1}		Total Hardness mg.l^{-1}.		Calcium Hardness mg.l^{-1}		Magnesium Hardness mg.l^{-1}	
	1	2	1	2	1	2	1	2
2. 5.77		1.65		331		216		115
30. 5.77	0.75	2.35	414	378	288	266	126	112
27. 6.77	1.35	2.5	424	362	296	250	128	112
26. 7.77	2.0	2.65	406	374	280	252	126	122
22. 8.77	1.7	2.5	404	320	282	220	142	100
20. 9.77	0.1	0.35	400	336	288	244	112	92
17.10.77	1.2	2.3	424	356	270	232	154	124
15.11.77	1.3		392		278		114	
13.12.77	1.0	1.25	370	324	260	216	110	108

TABLE A1.2 (cont.)

RIVER TRENT WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	TRENT 1		TRENT 2		TRENT 3		TRENT 4	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	11.0	3.5- 21.3	11.3	3.8- 17.0	12.1	4.2- 19.2	15.1	5.6- 26.5
pH	7.8	7.4- 8.4	7.4	7.1- 7.7	7.6	7.1- 8.0	7.7	7.3- 8.1
Susp.solids	25	1.8- 84	33	10 -256	26	8 - 74	29	8 -178
D.O. Conc$^{n.}$	10.3	7.3- 15.1	7.6	4.3- 10.2	9.1	7.5- 10.6	9.1	7.1- 11.5
D.O.% Sat$^{n.}$	97	71 -157	70.1	45 - 86	87.9	66 -107	92.7	76 -116
BOD_5	4.3	1.8- 9.6	10.2	4.0- 17.2	6.4	3.8- 15.8	6.2	2.5- 9.8
BOD_5 + ATU	2.8	1.0- 6.0	5.8	2.7- 11.0			4.2	1.4- 8.2
Chloride	133	35 -200	106	46 -143	95	53 -147	100	46 -155
Alkalinity	164	75 -200	142	85 -175	162	100 -305	161	105 -300
Total Hdns.	390	235 -500	335	235 -400	354	275 -425	370	300 -435
NH_3- N	0.3	<0.1- 0.8	1.3	0.3- 2.6	0.7	0.3- 1.5	0.5	<0.1- 1.1
Total Ox.N.	9.4	7.0- 12.0	12.5	10.0- 19.2	9.4	6.8- 12.0	10.1	7.5- 15.7
Orthophosphate	1.3	0.36- 2.3	1.9	0.54- 2.8			1.3	0.3- 2.5

TABLE A1.3

RIVER TAME PHYSICO-CHEMICAL DATA 1977

DATE / SITE	Temperature °C		Suspended Solids mg.l^{-1}		Dissolved Oxygen mg.l^{-1}		Dissolved Oxygen % Saturation	
	1	2	1	2	1	2	1	2
2. 5.77	11.3	11.4	26	21	7.5	6.6	71	63
30. 5.77	14.5	14.8	32	20	8.0	7.4	81	76
27. 6.77	15.0	15.0	18	17	7.4	6.9	76	71
26. 7.77	16.2	16.2	21	34	6.8	6.0	72	63
22. 8.77	16.1	16.2	35	22	6.5	6.1	68	64
20. 9.77			16	11	6.5			
17.10.77	13.0	12.0	17	10	6.4	5.2	63	50
15.11.77		8.0		31		7.4		65
13.12.77	10.0	8.5	32	46	8.4	8.8	77	78

DATE / SITE	Chloride mg.l^{-1}		Alkalinity mg.l^{-1}		Ammonia N mg.l^{-1}		Nitrate N mg.l^{-1}	
	1	2	1	2	1	2	1	2
2. 5.77	112	88	147.5	107.5	6.6	4.65	12.5	>20.0
30. 5.77	122	111	167.5	112.5	7.1	2.9	13.6	18.0
27. 6.77	121	91	170.0	115.0	7.35	3.5	9.8	15.7
26. 7.77	119	107	155.0	102.5	4.85	2.85	10.1	25.6
22. 8.77	76	94	105.0	102.5	2.2	7.5	10.5	5.1
20. 9.77	128	111	165.0	112.5	8.9	6.3	10.5	13.3
17.10.77	124	112	172.5	120.0	7.85	1.65	7.8	13.9
15.11.77		89		100.0		2.5		11.5
13.12.77	87	66	120.0	90.0	1.75	1.65	10.9	6.6

DATE / SITE	Phosphate P mg.l^{-1}		Total Hardness mg.l^{-1}		Calcium Hardness mg.l^{-1}		Magnesium Hardness m.g. l^{-1}	
	1	2	1	2	1	2	1	2
2. 5.77	2.5	2.5	359	293	242	202	117	91
30. 5.77	3.85	3.7	382	332	270	222	112	110
27. 6.77	3.8	3.25	368	308	262	212	106	96
26. 7.77	3.35	4.15	350	304	240	182	110	122
22. 8.77	3.1	1.9	246	284	175	198	71	86
20. 9.77	0.6	0.4	340	272	220	184	120	92
17.10.77	2.5	4.1	340	272	231	168	109	104
15.11.77.		3.0		278		178		100
13.12.77	1.0	1.1	304	326	228	206	76	120

TABLE A1.4

RIVER MEASE PHYSICO-CHEMICAL DATA 1977

DATE	Temperature °C	Suspended solids mg.l^{-1}	Dissolved Oxygen mg.l^{-1}	Dissolved Oxygen % Saturation	Chloride mg.l^{-1}.	Alkalinity mg.l^{-1}.	Ammonia N mg.l^{-1}.	Nitrate N mg.l^{-1}.	Phosphate mg.l^{-1}.	Total Hardness mg.l^{-1}.	Calcium Hardness mg.l^{-1}.	Magnesium Hardness mg.l^{-1}.
4. 4.77	5.5	14	13.2	108	106	147.5	1.1	10.1	Neg	463	272	181
2. 5.77	10.5	5	10.8	100	146	167.5	1.2	10.1	Neg.	464	292	172
30. 5.77	13.2	8	11.7	115	233	202.5	1.2	13.9	0.8	546	344	202
26. 7.77	14.8	15	8.3	85	270	210	1.15	6.9	1.35	564	238	126
22. 8.77	15.0	16	8.0	82	137	145	1.9	4.8	1.4	394	238	156
20. 9.77		12	10.5		304	202.5	1.8	7.5	Neg.	532	308	224
17.10.77	10.5	6	9.4	87	392	195	6.5	7.4	Neg.	538	364	174
15.11.77	5.5	14	11.0	91	131	152.5	0.85	7.5	1.15	434	272	62
13.12.77	7.0	38	11.1	95	94	112.5	1.25	11.8	0.35	426	278	148

TABLE A1.5

RIVER TEAN 1 PHYSICO-CHEMICAL DATA 1976-1977

DATE	Temperature °C	Suspended Solids mg.l-1.	Dissolved Oxygen mg.l-1.	Dissolved Oxygen %Saturation mg.l-1.	Chloride mg.l-1.	Alkalinity mg.l-1.	BOD_5 mg.l-1.	Ammonia N mg.l-1.	Nitrates -N.mg.l-1.	Phosphate -P mg.l-1.	Total Hardness.mg.l-1.	Calcium Hardness mg.l-1.	Magnesium Hardness mg.l-1.
8. 4.76		2.5	13.3		43			1.9	5.1	0.6	240	170	70
21. 4.76		1	10.5		37	135	1.1	1.9	4.3	0.6	248	177	71
19. 5.76		10	11.0		50	143	1.8	2.1	1.41	1.55	248	184	64
3. 6.76	11.5	3	9.2	88	43	134	3.2	2.2	1.3	1.75	252	180	72
16. 6.76	13.5	2	7.2	72	39	151		2.6	1.86	0.3	270	180	90
30. 6.76	16.5	9	8.2	86	36	142.5	3.1	2.81	1.99	0.4	236	182	54
13. 7.76	15.8	14	5.9	61	59	100	7.0	1.7	1.45	0.04	176	148	28
28. 7.76	13.6	11	9.3	92	35	146	1.5	1.1	1.58	0.2	236	182	54
25. 8.76.	13.6	8	9.9	98	35	140		1.15	1.7	0.55	238	180	58
8. 9.76	11.5	5	9.9	94	34	137.5	0.5	0.85	1.6	0.4	240	182	58
27. 9.76	13.0	7.5	8.9	87	64	78.8	3.0	1.25	3.55	0.45	258	200	58
3.11.76	5.0	5.5	10.8	88	41	83.8	0.82	0.9	2.4	2.15	212	156	56
25.11.76	7.8	0.5	10.9	95	40	107.5	0.9	1.0	2.2	1.8	242	176	66
22.12.76	4.0	18	12.0	95	68	67.5		0.7	4.8	0.85	192	148	44
19. 1.77	3.5	13	9.7	76	100	128.8	8.8	1.6		2.5	288	196	92
16. 3.77	7.0	102	10.2	87	41	95	6.8	1.25	1.7	0.5	190	142	48
13. 4.77	8.5	17	11.4	101	39	95		2.55	4.0	0.4	230	148	82
11. 5.77	10.2	4	10.1	93	33	100	3.8	0.45	5.0	0.05	214	154	60
9. 6.77	10.0	13	10.7	98	36	130	1.7	0.7	3.8	0.15	256	190	66
6. 7.77	14.0	16	9.3	93	37	140		0.65	4.3	0.25	256	186	70
3. 8.77	14.0	8	9.0	90	36	142.5					244	186	58
1. 9.77		5	10.15		41	137.5					246	180	66
29. 9.77		5	9.7		37	137.5		3.05	4.5	Neg.	240	196	44
25.10.77	9.7	2	9.9	90	68	130		0.5		0.1	244	180	64
22.11.77	4.5	7	12.1	97	65	80		1.3	6.0	Neg.	198	160	38
19.12.77		5	11.3		61	82.5		0.75	5.7		212	166	46

TABLE A15 (cont.)

RIVER TEAN 2 PHYSICO-CHEMICAL DATA 1976-1977

DATE	Temperature °C	Suspended Solids mg.l-1.	Dissolved Oxygen mg.l-1.	Dissolved Oxygen % Sat. mg.l-1.	Chloride mg.l-1.	Alkalinity mg.l-1.	BOD_5 mg.l-1.	Ammonia N mg.l-1.	Nitrates N mg.l-1.	Phosphate mg.l-1.	Total Hardness mg.l-1.	Calcium Hardness mg.l-1.	Magnesium Hardness mg.l-1.
8. 4.76		15.5	8.7		53.5			2.1	7.7	2.5	289	192	97
21. 4.76		18.5	8.9		72	167	5.65	1.9	7.3	2.4	312	190	122
19. 5.76		15	7.5		54	170	6.1	2.3	4.25	4.3	298	202	96
3. 6.76	12.0	5	4.95	47	58	153	4.75	2.3	3.78	3.9	284	188	96
16. 6.76	14.2	5.5	5.0	50	67	176		2.69	4.49	4.02	332	192	140
30. 6.76	18.5	8	7.2	79	53	177.5	5.1	3.0	4.58	4.4	286	188	98
13. 7.76	16.5	13.5	3.7	39	57	130		2.3	2.5	1.95	218	152	66
28. 7.76	14.6	8.5	4.2	42	80.5	169	8.1	1.2	6.0	5.2	298	194	104
25. 8.76	15.5	11.5	7.49	77	77	165		1.3	11.6	5.75	290	186	104
8. 9.76	12.1	6.5	8.7	88	74	160	5.0	1.15	8.15	5.6	310	190	120
27. 9.76	13.5	23	6.4	63	62	94	4.0	1.35	6.0	1.65	301	234	67
3.11.76	6.0	18.5	8.9	74	50	107.5	11.2	0.5	3.45	2.5	248	178	70
25.11.76	8.5	5	8.5	76	54	147.5	10.0	0.9	3.9	3.5	291	194	97
22.12.76	4.7	34.5	11.05	88	90	82.5		1.0	5.9	1.15	248	167	61
19. 1.77.	3.5	13	9.7	76	100	129	8.8	1.6		2.5	288	196	92
16. 3.77	7.5	24	9.3	80	48	125	13.5	1.55	2.9	0.1	242	168	74
13. 4.77	9.0	33	8.3	75	45	132.5		2.4	6.4	2.0	255	162	93
11. 5.77	10.9	12	7.4	69	45	132.5	6.4	1.0	8.7	1.0	246	176	70
9. 6.77	10.7	20	6.7	63	54	157.5	14.0	0.9	11.1	3.0	284	184	100
6. 7.77	14.8	12	4.4	45	50	165		0.85	10.0	3.75	286	198	88
3. 8.77	15.0	8	4.6	47	71	147.5					296	192	104
1. 9.77		13	6.1		67	147.5					280	192	88
29. 9.77		7	5.5		74	135		2.0	6.4	4.55	290	190	100
25.10.77	10.6	7	6.5	60	60	140		0.8	11.6	2.5	286	170	116
22.11.77	4.2	10	11.0	87	92	100		1.2	7.5	0.75	238	174	64
19.12.77		7	9.9		61	105		0.65	7.4		232	170	62

TABLE A1.6

RIVER TRENT TRIBUTARIES WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	TAME 1		TAME 2		DERWENT 1		DERWENT 2	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	12.4	4.0- 20.5	18	18	9.3	2.5 - 15.5	13.9	6.0- 22.2
pH	7.5	6.9- 8.8	7.8	7.8	7.8	7.5- 8.1	7.7	7.5- 8.0
Susp. solids	42	13 -256	21	21	16	6 - 46	13	7 - 31
D.O.Conc$^{n.}$	7.6	3.3- 9.6	8.9	8.9	10.8	9.0- 13.0	8.8	5.1- 11.4
D.O.% Sat$^{n.}$	71	32 - 96	97	97	99	89 -115	87.6	58 -128
BOD_5	12.1	5.5- 33.0	10.5	10.5	2.4	1.5- 4.4	3.9	0.6- 7.5
BOD_5 + ATU	10.3	4.5- 23.0						
Chloride	123	64 -345	110	110	62	39 - 93	79	43 -137
Alkalinity	190	135 -240	135	135	140	120 -160	160	120 -195
Total hdns.	369	190 -465	320	320	229	210 -265	286	230 -370
NH_3 - N	5.5	1.6- 10.0	3.7	3.7	0.2	$<$0.1- 0.3	0.4	$<$0.1- 0.8
Total Ox.N.	7.6	$<$0.2- 11.0	0.7	0.7	4.1	3.0- 6.4	4.8	3.2- 7.1
Orthophosphate	1.5	0.8- 2.7					0.5	0.5

TABLE A1.6 (cont.)

RIVER TRENT TRIBUTARIES WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	MEASE		TEAN 1		TEAN 2	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	10.1	1.5- 17.5	8.3	3.0- 12.2	10.5	3.0- 16.5
pH	7.9	7.3- 8.5	7.7	7.4- 8.0	7.7	7.3- 8.1
Susp. solids	30	<1 -382	19	4 - 61	35	4 -427
D.O.Conc$^{n.}$	10.3	5.9- 15.2	10.7	8.5- 11.8	9.7	7.5- 11.1
D.O.% Sat$^{n.}$	94	62 -140	93	79 -110	90	71 -102
BOD_5	2.4	0.5- 6.3	2.8	1.4- 6.0	5.1	2.2- 12.0
BOD_5 + ATU	2.1	0.5- 4.0			3.5	1.8- 6.2
Chloride	160	34 -410	34	29 - 41	46	25 - 93
Alkalinity	193	90 -265	118	90 -155	157	75 -200
Total Hdns.	463	295 -600	214	175 -250	268	150 -320
NH_3 - N	0.2	<0.1- 0.6	0.3	<0.1- 0.7	0.5	<0.1- 1.8
Total Ox.N.	10.3	5.2- 20.8	4.5	3.4- 5.7	8.8	4.7- 12.6
Orthophosphate	0.9	0.26- 1.4			2.0	0.34- 3.2

TABLE A1.7 RIVER CHURNET PHYSICO-CHEMICAL DATA 1977-1978

Current Velocity ($cm.sec.^{-1}$) (Riffles).

DATE	TRIB.	1	2	3	4	5	6	7	8	9	10	11	12	13
17. 3.77	106.3	20.3	75.6		54.7		121	51.3	116	63.1		108		90
14. 4.77	56.3	41.2	61.4	89.1	39.6	65.2	58.9	58.5	94.2	84.5	118	118	76.5	76.5
12. 5.77	23.6	44.2	109.7	109.7	33.7	49.2	114.3	52.2	155.9	59.3	135.6	83.2	127.3	109.7
10. 6.77	28.2	21.9	40.4	37.4	15.9	15.9	65.6	36.2	125.2	46.3	55.9	56.8	64.3	39.1
7. 7.77	24.4	17.9	31.6	47.1	11.6	33.7	49.6	50.1	126.1	47.1	124.4	34.1	71.9	35.8
4. 8.77	31.6	10.1	31.6	63.1	24.0	22.3	47.9	53.4	121.9	47.5	96.7	27.8	24.4	38.7
2. 9.77	37.9	9.7	14.0	22.3	20.7	24.0	63.1							
30. 9.77	19.1	6.9	8.9	30.3	16.4	11.6	56.4	29.5	120.2	30.3	42.1	22.3	49.6	27.8
26.10.77	34.1	14.3	22.3	33.3	30.3	10.8	47.5	31.6	140.8	24.0	48.8	43.3	56.2	33.3
23.11.77	22.3	86.2	68.5	72.3	66.9	27.8	107.2	46.3	137	63.5	131.1	100.9	125.3	109.7
21. 2.78	24.0	33.3	26.9	45.0	23.2	29.1	85.8	35.3	110.5	43.7	62.2	103.4	91.6	77.8
21. 3.78	67.7	79.0	90.8	85.6	69.8	80.7	83.7	81.9	142.5	144.6	123.9	110.1	153.8	68.1
18. 4.78	35.8	47.5	40.4	84.9	27.8	40.4	66.4	50.9	101.7	60.6	87.4	65.2	76.5	63.9

Temperature (^{o}C)

17. 3.77	7.2	5.5	6.3		6.0		7.0	8.1	7.8	7.9	7.9	7.9		7.9
14. 4.77	6.5	4.5	5.0	5.7	5.9	5.9	7.2	8.8	8.8	8.8	9.0	9.0	9.0	9.3
10. 6.77	8.5	9.4	9.4	9.7	9.4	10.5	13.4	15.2	14.0	12.0	12.0	12.0	12.1	12.2
7. 7.77	11.5	15.8	15.8	11.9	13.2	13.2	17.4	17.8	18.0	18.4	18.2	18.2	18.0	18.5
4. 8.77	10.2	12.2	12.0	12.0	12.0	12.0	13.5	13.5	13.7	14.0	14.0	14.0	14.5	14.5
30. 9.77	10.4	11.8	11.8	12.8	13.8	13.0	13.2	16.0	14.0	13.5	13.0	12.9	12.8	12.9
26.10.77	8.4	8.2	8.4	9.8	9.0	11.0	11.2	13.2	11.1	9.8	9.8	9.8	10.0	10.0
23.11.77	6.4	5.0	5.2	5.6	5.6	6.8	6.8	7.8	6.9	6.2	6.2	6.2	6.5	6.5
21. 2.78	5.0	0.7	1.9	2.3	1.9	2.1	2.1	4.4	2.2	2.0	2.0	2.2	2.2	2.2
21. 3.78	4.5	2.5	2.75	3.5	3.75	3.75	4.25	4.5	4.5	4.75	4.75	5.0	5.25	5.25
18. 4.78	6.0	5.0	6.0	5.5	5.75	6.25	8.25	9.5	8.25	8.0	7.75	8.0	8.0	8.0
17. 5.78	10.0	10.25	11.5	9.5	10.5	10.0	13.0	14.25	13.25	12.25	12.25	12.25	12.25	12.25

TABLE A1.7 (cont) RIVER CHURNET PHYSICO-CHEMICAL DATA 1977-1978

pH

DATE	TRIB.	1	2	3	4	5	6	7	8	9	10	11	12	13
17. 3.77	6.05	5.6	5.7		6.1		6.0	6.4	6.6	6.35	6.65	6.65		6.2
4. 8.77	6.9	7.2	7.4	6.5	7.1	6.8	7.0	7.0	6.7	6.7	7.0	7.2	7.4	7.4
21. 3.78	6.92	6.89	6.94	7.02	7.09	7.09	7.06	7.06	7.2	7.23	7.28	7.29	7.31	7.28
18. 4.78	7.13	6.91	7.1	7.12	7.16	7.2	7.02	7.0	7.22	7.21	7.26	7.29	7.3	7.23
17. 5.78	7.05	6.9	7.2	7.0	7.1	7.2	6.95	6.84	7.03	7.06	7.21	7.3	7.25	7.6

Suspended Solids ($mg.l^{-1}$).

17. 3. 77	16	6	4		2		5	12	7	11	12	8		0
4. 8. 77	4	3	5	5	6	5	10	14	8	8	7	24	11	11
2. 9. 77	4	7	11	11	5	8	7	7	10	13	6	7	10	5
30. 9. 77	2	0	4	5	0	2	8	9	6	7	10	3		2
26.10. 77	2	3	9	5	1	4	22	10	13	11	10	5	15	5
23.11. 77	1	14	1	2	5	3	12	2	0	5	1	0	7	4
21. 2. 78	3	5	4	6	3	2.5	16	12	11.5	15	16	12.5	13	9.5
21. 3. 78	8.5	16.3	14.3	17.8	35	26	47.8	51.5	51.5	76	85.5	99.5	98.5	99
18. 4. 78	2.5	6	3.5	7	6.5	12	10	11	29.5	9.5	4.5	6.5	6	6
17. 5. 78	0.5	0.5	12	2.5	4	0.5	5.5	8	7.5	7.5	5.5	3.5	10.5	7

TABLE A1.7 (cont.) RIVER CHURNET PHYSICO-CHEMICAL DATA 1977-1978

Dissolved Oxygen ($mg.l^{-1}$.)

DATE	TRIB.	1	2	3	4	5	6	7	8	9	10	11	12	13
17. 3.77	11.1	12.2	11.8		11.7		10.5	9.55	10.7	10.6	10.7	10.9		10.4
4. 8.77	10.7	9.4		10.2		8.5	2.7				9.7			10.5
2. 9.77	12.0	11.0	10.6	9.2	10.2	10.6	6.2	7.5	9.6	10.5	10.6	10.4	10.2	10.5
30. 9.77	10.55	10.1	10.1	9.6	9.3	8.4	3.95	5.0	7.7	9.4	9.5	9.5	9.5	9.5
26.10.77	10.9	12.0	11.8	11.8	10.7	9.6	5.3	6.3	8.7	9.9	10.0	10.5	10.5	10.7
23.11.77	11.6	12.3	12.1	12.0	11.7	11.7	9.6	10.5	11.5	11.5	11.9	11.6	11.6	11.6
21. 2.78	11.6	12.9	12.1	13.0	12.5	12.5	11.4	10.7	12.2	12.7	12.6	12.4	12.5	12.4
21. 3.78	12.1	12.86	12.48	12.0	11.9	12.1	11.3	11.2	11.6	11.3	11.0	10.8	11.2	11.3
18. 4.78	11.5	11.3	11.0	11.9	11.1	8.9	7.6	9.3	9.5	9.4	9.5	9.7	10.7	10.2
17. 5.78	11.1	11.4	11.4	12.2	12.2	11.4	8.3	7.2	9.0	9.8	11.2	11.3	11.0	12.6

Dissolved Oxygen % Saturation

17. 3.77	96	100	99		97		90	84	94	92	94	95		91
4. 8.77	99	91		98		81	27				97			107
30. 9.77	97.5	97	97	94	93	82	39	52	77	93	93	93	93	93
26.10.77	96	105	104	108	96	91	51	62	82	91	92	96	96	98
23.11.77	97	100	99	99	97	100	82	92	98	97	100	97	98	98
21. 2.78	94	93	90	97	93	94	86	85	92	94	94	93	94	94
21. 3.78	97	96	95	93	93	95	90	90	93	92	89	88	92	93
18. 4.78	96	91	93	97	93	75	67	84	83	82	82	85	94	90
17. 5.78	102	105	108	110	114	105	82	73	89	95	108	109	106	122

TABLE A1.7(cont.) RIVER CHURNET PHYSICO-CHEMICAL DATA 1977-1978

BOD_5 ($mg.l^{-1}$).

DATE	TRIB.	1	2	3	4	5	6	7	8	9	10	11	12	13
4. 8.77	1.1	1.9		1.2			33.0				1.9			1.7
2. 9.77	2.1	1.7	1.1	1.1	1.0	0.3	3.3	5.3	2.7	2.1	2.5	1.5	1.7	1.6
30. 9.77	1.05	1.7	0.6	1.4	1.3	7.3	7.3	9.3	4.9	2.6	2.2	1.8	1.8	1.8
26.10.77	1.7	1.4	1.4	2.0	1.2	13.5	13.5	17.5	10.5	9.1	8.4	4.5	2.9	2.4
23.11.77	0.7	0.8	0.5	1.3	2.0	4.8	9.9	6.8	3.8	2.6	2.6	2.3	2.3	2.1
21. 2.78	0.9	1.85	1.5	1.4	1.1	12.5	18.2	29.7	2.2	2.9	2.7	1.9	2.4	2.5
18. 4.78	1.3	1.2	0.8	1.8	1.5	1.6	5.8	10.0	4.5	2.3	1.9	1.9	1.7	2.1
17. 5.78	1.3	1.0	1.2	1.4	2.4	1.7	4.1	7.15	6.2	3.5	2.7	1.7	3.5	2.2

NH_3-N ($mg.l^{-1}$.)

17. 3.77	0.45	0.5	0.5		1.1		1.2	1.55	1.2	1.2	1.05	1.05		1.0
14. 4.77	1.1	1.5	0.5	1.25	0.65	0.85	2.25	2.7	2.7	2.3	2.25	0.95	2.05	0.65
4. 8.77	1.6	0.65	1.15	0.65	1.0	1.75	2.0	3.5	1.85	1.0	1.0	0.85	1.15	0.85
30. 9.77	0.7	0.65	0.65	0.7	0.75	0.8	1.15	1.2	0.9	5.0	1.2	0.5		0.75
26.10.77	0.5	0.5	0.5	0.65	0.7	0.8	1.65	2.15	1.4	1.35	0.85	0.8	0.7	0.7
23.11.77	0.65	0.65	0.6	0.7	1.25	1.15	1.0	1.25	1.2	0.9	0.9	0.85		0.85
21. 2.78	1.2	1.6	1.6	0.95	2.4	2.5	4.1	4.7	2.5	1.9	2.8	1.9	1.7	1.6
21. 3.78	0.8	0.6	0.35	0.6	0.6	0.8	1.2	1.35	1.2	1.3	0.8	1.55	1.4	1.65
18. 4.78	0	0	0	0.4	0.6	0.5	1.6	2.3	0.7	0.7	0.3	0.4	0.2	0.2
17. 5.78	0	0	0	0.1	0.3	0.3	1.7	2.9	1.3	0.7	0.2	0.2	0.2	0.1

TABLE A1.7 (cont.) RIVER CHURNET PHYSICO-CHEMICAL DATA 1977-1978

Chloride $mg.l^{-1}$.

DATE	TRIB.	1	2	3	4	5	6	7	8	9	10	11	12	13
17. 3.77	30	33	30		31		44	47	43	43	54	44		43
4. 8.77	20	25	22	26	25	29	76	86	56	65	59	45	45	43
2. 9.77	28	31	27	31	33	38	45	43	45	45	43	51	51	51
30. 9.77	25	24	26	24	27	32	99	132	68	70	66	52		57
26.10.77	21	25	28	31	36	35	84	84	60	58	47	49	49	49
23.11.77	29	36	32	32	41	42	64	61	58	48	47	50	47	47
21. 2.78	23	41	26	35	32	39	51	54	34	32	32	32	34	35
21. 3.78	25	42	27	28	29	30	33	33	30	31	31	37	37	39
18. 4.78	23	41	48	36	58	40	60	58	36	38	36	38	38	38
17. 5.78	22	26	19	25	29	30	61	58	42	46	34	36	40	38

Alkalinity $mg.l^{-1}$

17. 3.77	28.75	15	15		23.75		47.5	50	47.5	45	47.5	60		60
4. 8.77	45	37.5	37.5	35	35	37.5	80	75	70	62.5	67.5	72.5	80	80
2. 9.77	47.5	30	37.5	37.5	37.5	37.5	65	70	75	70	75	82.5	70	72.5
30. 9.77	50	37.5	42.5	37.5	37.5	40	80	90	102.5	85	82.5	85		82.5
26.10.77	42.5	12.5	22.5	37.5	42.5	47.5	75	67.5	62.5	65	65	75	82.5	87.5
23.11.77	25	12.5	15	30	40	37.5	62.5	62.5	55	52.5	52.5	55	61	60
21. 2.78	40	32	35	35	45	45	75	80	80	65	65	75	85	90
21. 3.78	20	15	17.5	30	30	35	55	55	54	50	55	60	65	65
18. 4.78	40	18.5	30	35	50	45	90	65	67.5	65	70	75	80	80
17. 5.78	47.5	20	32.5	35	42.5	47.5	85	80	85	80	80	95	90	90

TABLE A1.7 (cont.) RIVER CHURNET PHYSICO-CHEMICAL DATA 1977-1978

Total Hardness (mg. l^{-1}. $Ca.CO_3$)

DATE	TRIB.	1	2	3	4	5	6	7	8	9	10	11	12	13
17. 3.77	87	57	60		85		110	110	118	128	143	142		148
4. 8.77	108	82	88	100	86	94	140	160	162	220	218	196	230	216
2. 9.77	94	96	88	126	102	92	128	138	151	210	196	202	224	218
30. 9.77	88	98	92	104	94	94	156	188	176	232	216	206		240
26.10.77	86	100	92	106	102	116	174	172	176	232	210	246	271	206
23.11.77	80	78	66	112	120	116	138	144	150	166	160	164	173	176
21. 2.78	87	71	83	73	93	92	129	138	142	167	162	173	194	198
21. 3.78	66.5	53	58.2	79.8	82	85.8	109	110.2	106.5	115	120	121.5	128	131
18. 4.78	76.5	59.5	66	82	93.5	94	122	125.5	132	183	178.5	171	180	181
17. 5.78	80	58.2	65.5	76.5	83.2	88.8	126.5	131	141.2	164.5	158.8	167.5	182	182

Calcium Hardness (mg.l^{-1}. $CaCO_3$)

17. 3.77	50	38	52		59		85	90	92	102	106	108		116
4. 8.77	56	56	54	66	64	66	112	120	124	176	170	150	178	174
2. 9.77	54	56	54	64	62	68	92	94	112	164	156	160	174	168
30. 9.77	52	56	54	58	72	66	118	144	136	194	184	166		180
26.10.77	52	50	46	72	72	70	110	124	126	188	164	194	168	156
23.11.77	48	42	42	84	92	86	112	114	122	136	130	122	128	130
21. 2.78	50	47	63	47	65	68	100	108	112	135	131	137	153	155
21. 3.78	45	41	45.5	65	66	69	91.5	92.5	89	96	99	100.5	104	106
18. 4.78	48	54.5	49	66.5	72	73	100	101.5	108	154	152	141	144	144
17. 5.78	52.5	48	49.5	61.5	64.5	69	102	105.5	115	127	127.5	133	148.5	142

TABLE A1.7 (cont.) RIVER CHURNET PHYSICO-CHEMICAL DATA 1977-1978

Nitrates NO_3-N (mg. l^{-1}.)

DATE	TRIB.	1	2	3	4	5	6	7	8	9	10	11	12	13
17. 3.77	1.1	0.5	0.6		1.15		1.55	1.6	1.65	1.6	1.6	1.6		1.7
4. 8.77	1.75	1.95	1.1	1.2	1.3	1.2	1.3	2.85	4.8	5.3	3.8	3.8	3.9	4.0
2. 9.77	0.8	4.6	1.1	1.0	1.25	1.3	4.1	4.2	4.35	3.9	3.6	3.4	3.0	3.0
30. 9.77	2.05	1.0	1.9	1.2	1.4	1.3	2.65	1.5	3.3	4.6	4.45	4.8		5.65
26.10.77	1.9	0.7	0.9	1.5	1.7	1.8	4.2	5.2	6.65	6.4	6.2	5.8	5.0	4.6
23.11.77	2.5	0.9	1.3	2.3	2.4	2.6	4.45	4.6	5.1	5.1	4.9	5.1		5.1
21. 2.78	2.1	1.8	1.9	1.5	2.0	2.0	3.4	3.95	4.15	4.3	2.2	3.8	3.7	3.95
18. 4.78	1.9	0.6	1.0	1.6	1.8	1.8	2.9	3.4	3.6	4.1	3.6	3.3	3.3	3.4
17. 5.78	1.6	0.4	0.7	1.6	1.6	1.6	3.5	3.9	4.7	4.4	4.1	4.3	4.7	4.6

Phosphates PO_4 -P (mg.l^{-1}.)

17. 3.77	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4. 8.77	0.2	0.4	0	0.15	0	0	0.4	0.2	0.2	0.6	0.4	0.4	0.3	0.4
2. 9.77	Neg.	0.7	0.1	Neg.	Neg.	Neg.	0.5	0.6	0.4	Neg.	0.1	0.4	0.2	Neg.
30. 9.77	0.1	0.1	0.1	Neg.	Neg.	Neg.	0.2	0.1	0.2	Neg.	Neg.	0.2		Neg.
26.10.77	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
23.11.77	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
21. 2.78	0.55	0.4	0.25	0.4	0.25	0.3	0.5	0.55	0.5	0.5	0.5	0.4	0.55	0.5
18. 4.78	0.2	0.2	<0.2	0.2	<0.2	<0.2	0.4	0.4	0.5	0.2	0.2	0.2	0.2	0.2
17. 5.78	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.4	0.2	0.2	<0.2	<0.2	0.2	<0.2

TABLE A1.7 (cont.)

RIVER CHURNET PHYSICO-CHEMICAL DATA 1977-1978

Heavy Metals ($mg.l^{-1}$)

DATE	CADMIUM				CHROMIUM				LEAD			
SITE	3	6	8	13	3	6	8	13	3	6	8	13
4. 8.77	.002	.002	.002	.002	0	0	0	0	.02	.02	.02	.02
2. 9.77	.002	.002	.002	.002	.01	.01	.03	.01	.02	.02	.02	.02
30. 9.77	.002	.002	.002	.002	.01	.01	.02	.02	0	.02	.02	.02
26.10.77	.002	.002	.002	.002	0	.01	.02	.01	.02	.02	.02	.01
23.11.77	.002	.001	.001	.001	0	0	.01	.01	.02	.02	.02	.02
21. 3.78	.002	.002	.002	.002	0	0	.01	.01	.01	.02	.02	.03
18. 4.78	.001	.001	.002	.001	0	.01	.01	0	.01	.02	.02	.01
17. 5.78	.001	.001	.002	.002	0	0	0	0	.01	.02	.02	.02

DATE	COPPER				NICKEL				ZINC			
SITE	3	6	8	13	3	6	8	13	3	6	8	13
4. 8.77	.01	.02	.02	.044	.05	.1	.1	.05	.06	.04	.01	.02
2. 9.77	.022	.022	.024	.022	.01	.01	.01	.01	.05	.11	.04	.05
30. 9.77	.024	.026	.028	.022	.005	.01	.01	.005	.03	.06	.05	.04
26.10.77	.012	.012	.022	.018	.01	.015	.015	.015	.01	.03	.03	.02
23.11.77	.008	.014	.022	.022	.015	.015	.015	.015	.08	.04	.05	.04
21. 3.78	.002	.004	.012	.038	.015	.015	.015	.02	.01	.02	.03	.05
18. 4.78	.002	.004	.044	.014	.01	.01	.01	.01	0	0	.02	0
17. 5.78	.002	.004	.06	.022	.01	.01	.01	.01	.03	.01	.01	0

TABLE A1.7(cont.)

RIVER CHURNET WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	CHURNET 1		CHURNET 2		CHURNET 3		CHURNET 4	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	9.5	2.3- 16.0	9.0	4.0-16.0	8.8	2.0- 14.7	9.1	1.7- 16.0
pH	7.3	6.3- 8.0	7.2	6.9- 7.4	7.4	7.1- 7.9	7.5	7.2- 8.0
Susp. solids	8	1 - 29	5	3 - 6	6	2 - 14	8	2 - 39
D.O.Conc$^{n.}$	11.0	9.7- 12.2	12.1	11.0-13.2	10.8	8.0- 12.3	11.1	9.2- 12.6
D.O.% Sat$^{n.}$	98	90 -104	105	101 -112	96	80 -114	99	91 -116
BOD_5	1.4	0.5- 3.1	2.3	1.4- 3.8	2.4	0.7- 8.1	1.9	0.4- 5.4
BOD_5 + ATU							1.5	0.5- 4.0
Chloride	19	11 - 44	17	15 -20	20	14 - 35	22	13 - 38
Alkalinity	30	12 - 60	37	22 -54	40	20 - 65	48	25 - 65
Total Hdns.	70	45 -105	69	60 -83	89	50- -135	93	65 -140
NH_3 - N	0.1	0.03- 0.2	0.1	0.1	0.2	<0.1- 0.7	0.4	<0.1- 1.3
Total O.N.	0.9	0.3- 2.3	1.3	0.9- 1.7	1.7	1.0- 2.7	1.7	1.1- 2.7
Orthophosphate			<0.1	0.05 -0.14			0.1	0.02- 0.16

TABLE A1.7 (cont.)

RIVER CHURNET WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	CHURNET 5		CHURNET 6		CHURNET 7		CHURNET 8	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	9.9	2.4- 14.0	10.2	2.5- 17.5	11.7	3.0- 18.8	10.4	2.5- 17.0
pH	7.5	7.3- 7.9	7.3	7.1- 7.5	7.3	6.8- 7.6	7.3	7.2- 7.9
Susp. solids	5	4 - 8	13	5 - 38	12	4 - 55	13	5 - 76
D.O.Conc$^{n.}$	10.5	9.4- 11.8	9.1	6.0- 11.3	7.9	4.8- 11.6	9.9	7.5- 11.8
D.O.% Sat$^{n.}$	96	90 -106	84	64 -102	74	50 - 96	90	74 -102
BOD_5	13.0	1.7->51	4.7	2.9- 7.2	6.8	2.9- 12.0	5.1	2.6- 11.0
BOD_5 + ATU					6.2	2.8- 8.8		
Chloride	24	18 - 33	47	31 - 88	53	30 - 90	38	21 - 62
Alkalinity	46	35 - 55	70	40 -105	81	45 -105	73	45 -100
Total Hdns.	101	75 -155	129	105 -165	139	105 -175	147	105 -175
NH_3 - N	0.3	0.1- 1.1	1.1	0.3- 2.3	1.8	0.4- 5.8	0.9	<0.1- 2.7
Total Ox.N.	1.9	1.2- 2.4	3.6	2.3- 4.6	4.1	2.7- 6.8	4.1	3.2- 5.4
Orthophosphate					0.2	0.01- 0.4		

TABLE A1.7 (cont.)

RIVER CHURNET WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	CHURNET 9		CHURNET 10		CHURNET 11		CHURNET 12	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	9.6	2.5- 16.7	10.0	2.9- 16.3	11.8	8.0- 16.0	10.2	3.0- 16.0
pH	7.4	7.2- 7.9	7.4	7.2- 7.9	7.6	7.1- 7.9	7.4	7.0- 7.8
Susp. solids	15	4 - 63	19	3 -127	6	3 - 8	20	3 -121
D.O.Conc$^{n.}$	9.9	8.7- 11.5	10.4	9.3- 11.5	9.9	8.5- 10.8	10.1	8.4- 12.0
D.O.% Sat$^{n.}$	90	85 - 98	95	88 -106	94	85 - 99	93	82 -103
BOD_5	3.5	2.0- 5.8	3.4	0.7- 5.8	3.3	1.6- 5.0	3.4	1.1- 5.9
BOD_5 + ATU							2.7	1.1- 4.1
Chloride	36	27 - 54	33	26 - 42	37	31 - 45	39	26 - 62
Alkalinity	75	45 -105	77	45 -100	96	70 -120	85	45 -115
Total Hdns.	168	105 -215	170	110 -215	191	160 -235	185	115 -240
NH_3 - N	0.6	<0.1- 2.4	0.4	<0.1- 1.0	0.3	<0.1- 0.7	0.3	<0.1- 0.7
Total O.N.	4.1	3.0- 5.0	4.1	3.2- 5.3	3.6	2.8- 4.3	4.0	3.2- 5.0
Orthophosphate							0.1	0.06- 0.3

TABLE A1.8 RIVER SEVERN WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	SEVERN 1		SEVERN 2	
	MEAN	RANGE	MEAN	RANGE
Temperature	11.3	2.0- 23.5	11.3	4.0- 22.0
pH	7.9	6.9- 9.0	7.9	6.7- 9.0
Susp.solids	33	6 -180	35	8 -151
D.O.Conc$^{n.}$	11.4	9.4- 15.6	11.7	11.1- 12.8
D.O.% Sat$^{n.}$	101	85 -150	94	78 -120
BOD_5	2.5	1.0- 5.5	2.8	1.3- 7.0
BOD_5 + ATU	2.2	1.0- 3.7	2.1	0.9- 3.5
Chloride	29	8 - 51	45	13 - 87
Alkalinity	85	35 -135	110	43 -163
Total Hdns.	156	67 -430	192	91 -294
NH_3 - N	0.1	<0.1- 0.4	0.2	<0.01- 0.5
Total Ox.N.	4.6	1.5- 9.6	5.5	1.6- 9.2
Orthophosphate	0.2	0.03- 0.53	0.3	0.03- 0.9

TABLE A1.9

RIVER WYE WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	WYE 1		WYE 2	
	MEAN	RANGE	MEAN	RANGE
Temperature	10.8	3.5- 19.0	10.3	1.8- 19.0
pH	7.6	7.2- 8.5	7.9	7.3- 9.0
Susp. solids	22.5	4.0- 99.0	29.40	4.0-145.0
D.O. Conc$^{n.}$	10.4	9.4- 12.5	10.9	8.4- 13.0
D.O. % Sat$^{n.}$	91.8	85.0-101.5	95.0	83.0-126.0
BOD_5	2.2	0.7- 5.7	1.6	0.4- 3.3
Chloride	13.8	8.0- 22.0	15.2	9.0- 23.0
Alkalinity	53.7	23.0- 96.0	89.1	29.0-142.0
Total Hdns.	69.8	35.0-120.0	117.2	50.0-174.0
NH_3-N	0.1	0.01- 0.23	0.09	0.01- 0.26
NO_3-N	1.3	0.8- 1.76	3.3	1.0 - 6.9
Orthophosphate	0.07	0.01- 0.31	0.09	0.01- 0.3

TABLE A1.10

RIVER NENE PHYSICO-CHEMICAL DATA 1977

DATE / SITE	Temperature °C			Suspended Solids mg.l^{-1}			Dissolved Oxygen mg.l^{-1}.			Dissolved Oxygen % Saturation		
	1	2	3	1	2	3	1	2	3	1	2	3
6. 4.77	7.5	7.3	7.5	12	16	14	11.74	10.8	11.3	101	93	98
3. 6.77	17.0	16.8	16.0	14	20	34	13.8	11.7	15.1	146	124	157
30. 6.77	15.5	15.4	15.8	8	18	18	12.4	12.4	12.4	128	127	129
25. 8.77	14.9	14.2	14.8	12	12	11	8.9	7.9	9.6	91	79	97
21. 9.77	13.0	13.0	13.1	4	9	6	8.8	9.3	10.3	86	92	101
16.11.77				10	6	8	9.55	10.1	11.2			
14.12.77				10	6	20	10.9	10.9	11.9			

DATE / SITE	Chloride mg. l^{-1}.			Alkalinity mg. l^{-1}.			Ammonia N mg.l^{-1}			Nitrate N mg. l^{-1}.		
	1	2	3	1	2	3	1	2	3	1	2	3
6. 4.77	59.5	61.5	70.5	142.5	160	170	1.3	1.8	1.25	10.9	11.4	11.1
3. 6.77	75	92	92	150	160	170	0.85	1.15	0.9	8.6	15.6	14.0
30. 6.77	75	74	79	170	172.5	177.5	0.75	0.85	0.85	12.7	13.0	8.3
25. 8.77	56.5	63	61.5	137.5	145	130				5.8	7.1	7.0
21. 9.77	70	90	101	167.5	162.5	165	1.3	2.1	1.1	9.8	12.0	9.5
16.11.77	77	85	104	157.5	157.5	157.5	1.35	1.65	0.5	10.9	12.3	11.5
14.12.77	58	58	60	137.5	142.5	127.5	1.15	1.0	1.15	11.6	12.5	12.3

DATE / SITE	Phosphate mg.l^{-1}.			Total Hardness mg.l^{-1}			Calcium Hardness mg.l^{-1}			Magnesium Hardness mg.l^{-1}		
	1	2	3	1	2	3	1	2	3	1	2	3
6. 4.77	0.75	1.0	0.75	342	386	436	300	346	370	42	40	66
3. 6.77	0.9	2.15	0.6	338	382	452	276	332	378	62	50	74
30. 6.77	1.15	1.25	1.85	358	392	420	308	330	362	50	62	58
25. 8.77	0.1	0.5	0.1	284	324	322	260	298	294	24	26	28
21. 9.77	1.9	2.35	1.6	360	388	404	292	324	376	68	64	28
16.11.77	1.65	1.85	Neg.	322	366	408	276	292	330	46	74	78
14.12.77	0.3	0.5	0.35	348	370	344	284	324	312	64	46	32

TABLE A1.10 (cont.)

RIVER NENE WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

	NENE 1		NENE 2		NENE 3	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	11.6	4.0- 16.0	13.0	4.0- 17.0	11.1	2.0- 19.0
pH	8.04	7.8- 8.2	8.1	7.9- 8.4	8.3	7.8- 9.3
Susp.solids	15	5 - 29	15	5 - 31	17	2 - 78
D.O. Conc$^{n.}$	9.1	1.6- 12.7	9.0	4.7- 12.3	11.2	7.5- 14.3
D.O. % Sat$^{n.}$	82	16 -118	84	48 -104	101	84 -154
BOD_5	6.9	4.1- 13.5	10.5	2.0- 27.0	4.4	1.2- 12.5
BOD_5 +ATU					4.0	1.2- 12.5
Chloride	78	60 - 99	69	45 - 82	71	31 -101
Alkalinity	206	170 -230	208	185 -245	201	145 -235
NH_3 - N	1.3	0.03- 4.0	1.29	0.45- 2.5	0.31	<0.05- 2.4
NO_3 - N	13.8	10.5- 16.7	13.4	11.7 -17.7	13.6	6.8- 19.6
Orthophosphate					0.75	0.19- 2.1

TABLE A1.11

YORKSHIRE WATER AUTHORITY PHYSICO-CHEMICAL DATA 1977

RIVER AVON WATER AUTORITY PHYSICO-CHEMICAL DATA 1977

	FOSS		DON		AVON	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Temperature	10.5	2.0- 18.0	14.0	7.0- 25.0	10.4	1.0- 15.0
pH	7.8	7.4- 8.3	7.4	7.3- 7.8	8.1	7.8- 8.4
Susp. solids	21	6 - 69	28	10 - 83	28	3 -230
D.O.Conc$^{n.}$	9.9	6.1- 12.4	7.6	4.3- 11.8		
D.O. % Sat$^{n.}$	89	65 -107	75	48 -103	91	82 -110
BOD_5	2.5	1.6- 3.7	9.1	3.6- 22.1	3.7	1.6- 10.8
BOD_5 + ATU			6.8	6.8		
Chloride	61	33 - 97	265	109 -370	34	22 - 45
Alkalinity	181	130 -250	142	80 -184		
Total Hdns.	343	283 -404				
NH_3 - N	0.1	<0.1- 0.2	11.6	2.9- 19.6	0.4	0.08- 1.0
NO_3 - N	14.3	6.6- 22.1	6.1	4.6- 8.5	6.6	4.7- 12.5
Orthophosphate	3.3	<0.1- 12.8	1.1	<0.1- 3.3	0.5	0.1- 0.86

TABLE A1.12

SOUTH DRAIN PHYSICO-CHEMICAL DATA 1977

DATE	Temp. oC	Susp. Solids $mg.l^{-1}$	Diss. Oxygen $mg.l^{-1}$	Diss. Oxygen %Sat.	Chloride $mg.l^{-1}$	Alkalin. $mg.l^{-1}$	Ammonia N $mg.l^{-1}$.	Nitrates N. $mg.l^{-1}$	Phosphate P $mg.l^{-1}$.	Total Hdns. $mg.l^{-1}$	Calcium Hdns. $mg.l^{-1}$.	Magnesium Hdns. $mg.l^{-1}$.
18. 4.77	10.8	16	14.25	134	49	212.5	0.5	5.4	0.65	354	304	50
17. 5.77	12.5	15	14.0	135	90	235.0	0.85	2.7	0.15	348	292	56
11. 7.77	20.0	6	4.8	54	71	217.5	0.75	<0.05	0.75	308	260	48
8. 8.77	20.4	10	4.3	49	88	240.0	1.15	0.2	1.25	336	274	62
5.10.77	12.2	8	7.7	74	79	235.0	0.7	3.6	0.55	340	280	60
31.10.77	12.0	17	7.0	67	96	252.5				330	266	64
30.11.77		10	9.4		80	217.5	1.2	2.6	0.35	356	264	92

TABLE A1.13 RIVER TEAN PHYSICO-CHEMICAL DATA 1978

Date	1.3.1978				15.3.1978			
STATION	1	2	3	4	1	2	3	4
Current velocity cm sec^{-1}	-	-	-	-	83.7	66.0	54.7	93.7
Temperature ^{o}C	-	-	-	-	7.0	8.6	7.4	7.2
Suspended solids	-	-	-	-	4.80	17.20	15.60	20.80
Chlorides	-	-	-	-	43.0	92.0	48.0	50.0
Alkalinity	-	-	-	-	130.0	155.0	180.0	175.0
Total hardness	-	-	-	-	219.0	264.0	274.0	286.0
Ca hardness	-	-	-	-	162.0	186.0	190.0	204.0
Mg hardness	-	-	-	-	57.0	78.0	84.0	82.0
pH	-	-	-	-	7.6	7.5	7.5	7.6
Dissolved oxygen	-	-	-	-	11.9	10.1	10.8	11.1
BOD	-	-	-	-	-	-	-	-
Ammonia	1.20	1.25	1.30	1.10	0.75	1.45	1.40	1.35
Nitrates	4.40	5.90	5.50	5.50	3.60	5.80	5.30	5.80
Phosphates	0.40	2.05	1.50	1.90	0.30	2.20	1.30	1.70
Cadmium	0.001	0.003	0.003	0.003	0.002	0.003	0.003	0.003
Chromium	0.000	0.030	0.020	0.020	0.000	0.030	0.020	0.020
Copper	0.010	0.020	0.016	0.018	0.012	0.032	0.024	0.024
Lead	0.010	0.030	0.030	0.030	0.010	0.040	0.020	0.030
Nickel	0.010	0.015	0.010	0.010	0.010	0.025	0.015	0.020
Zinc	0.060	0.130	0.080	0.070	0.080	0.140	0.110	0.110

TABLE A1.13 (cont.)

Date	30.3.1978				11.4.1978			
STATION	1	2	3	4	1	2	3	4
Current velocity cm sec^{-1}	75.2	72.3	68.5	41.7	61.4	67.3	84.1	14.8
Temperature ^{o}C	6.8	7.8	6.9	7.0	5.0	6.6	5.0	5.2
Suspended solids	6.75	11.75	15.50	11.50	11.0	17.00	11.00	11.50
Chlorides	34.0	59.0	45.0	43.0	68.0	89.0	87.0	66.0
Alkalinity	113.0	160.0	160.0	155.0	145.0	175.0	185.0	193.0
Total hardness	190.0	226.0	250.0	262.0	240.0	270.0	294.0	288.0
Ca hardness	152.0	172.0	178.0	178.0	180.0	192.0	202.0	200.0
Mg hardness	38.0	54.0	72.0	84.0	60.0	78.0	92.0	88.0
pH	7.5	7.3	7.4	7.5	7.6	7.3	7.4	7.6
Dissolved oxygen	11.2	9.8	10.1	11.0	12.1	10.1	10.0	11.7
BOD	-	-	-	-	-	-	-	-
Ammonia	0.85	1.30	1.90	1.15	0.30	3.00	3.20	2.40
Nitrates	4.00	4.80	5.20	6.00	4.40	5.90	6.60	7.70
Phosphates	0.60	1.80	1.70	1.70	0.80	3.40	3.20	3.20
Cadmium	0.001	0.002	0.001	0.001	0.001	0.003	0.003	0.003
Chromium	0.000	0.010	0.010	0.010	0.000	0.010	0.030	0.020
Copper	0.002	0.008	0.008	0.008	0.002	0.010	0.016	0.014
Lead	0.010	0.010	0.010	0.010	0.020	0.020	0.030	0.030
Nickel	0.010	0.015	0.010	0.010	0.005	0.015	0.020	0.020
Zinc	0.020	0.050	0.050	0.040	0.050	0.050	0.100	0.090

TABLE A1.13 (cont.)

Date	25.4.1978				9.5.1978			
STATION	1	2	3	4	1	2	3	4
Current velocity cm sec.$^{-1}$	69.0	50.0	53.8	7.7	-	-	-	-
Temperature ^{o}C	8.7	9.5	8.6	8.2	9.9	10.7	9.9	11.0
Suspended solids	5.00	16.75	20.75	10.00	10.25	22.00	12.50	5.75
Chlorides	33.0	54.0	52.0	48.0	39.0	53.0	51.0	52.0
Alkalinity	130.0	175.0	180.0	180.0	120.0	175.0	175.0	170.0
Total hardness	232.0	262.0	276.0	276.0	224.0	234.0	270.0	272.0
Ca hardness	172.0	182.0	200.0	194.0	172.0	164.0	184.0	190.0
Mg hardness	60.0	80.0	76.0	82.0	52.0	70.0	86.0	82.0
pH	7.6	7.4	7.4	7.7	7.6	7.5	7.4	7.6
Dissolved oxygen	11.4	9.6	8.6	10.6	11.8	10.4	9.6	11.6
BOD	2.2	-	-	5.6	2.6	-	-	4.4
Ammonia	0.20	1.00	1.40	0.30	0.20	0.70	0.70	0.40
Nitrates	3.70	6.00	6.50	5.20	3.70	6.00	7.40	7.30
Phosphates	0.20	2.70	2.90	1.60	0.70	2.60	2.40	2.20
Cadmium	0.002	0.003	0.003	0.002	0.002	0.003	0.004	0.003
Chromium	0.000	0.030	0.020	0.010	0.000	0.020	0.030	0.020
Copper	0.002	0.016	0.016	0.008	0.002	0.020	0.016	0.010
Lead	0.020	0.020	0.020	0.010	0.020	0.050	0.030	0.020
Nickel	0.010	0.015	0.020	0.020	0.010	0.020	0.020	0.015
Zinc	0.050	0.070	0.070	0.030	0.010	0.130	0.090	0.040

TABLE A1.13 (cont.)

Date	24.5.1978				6.6.1978			
STATION	1	2	3	4	1	2	3	4
Current velocity cm sec^{-1}	-	-	-	-	-	-	-	-
Temperature ^{o}C	11.2	12.1	12.1	13.0	13.8	14.8	14.7	15.9
Suspended solids	5.00	13.50	7.50	8.00	7.00	17.00	9.75	46.25
Chlorides	32.0	48.00	58.0	57.0	33.0	76.0	64.0	50.0
Alkalinity	155.0	185.0	185.0	190.0	140.0	180.0	180.0	170.0
Total hardness	250.0	276.0	296.0	296.0	230.0	264.0	290.0	256.0
Ca hardness	190.0	198.0	212.0	206.0	180.0	190.0	204.0	188.0
Mg hardness	60.0	78.0	84.0	90.0	50.0	74.0	86.0	68.0
pH	7.4	7.3	7.4	7.6	7.5	7.3	7.3	7.3
Dissolved oxygen	9.9	7.8	7.4	9.4	9.2	8.2	7.3	5.2
BOD	1.8	3.3	0.3	3.3	2.8	5.3	4.6	4.4
Ammonia	0.30	0.30	0.30	0.20	0.30	0.40	0.40	0.60
Nitrates	3.60	6.50	8.30	8.50	3.60	6.10	8.80	4.80
Phosphates	0.70	2.40	3.00	3.00	0.70	3.00	3.20	2.40
Cadmium	0.001	0.003	0.003	0.003	0.002	0.002	0.001	0.002
Chromium	0.000	0.030	0.040	0.040	0.010	0.020	0.000	0.020
Copper	0.000	0.014	0.014	0.012	0.014	0.026	0.006	0.028
Lead	0.020	0.030	0.030	0.020	0.040	0.040	0.040	0.040
Nickel	0.010	0.015	0.020	0.020	0.015	0.015	0.005	0.010
Zinc	0.000	0.070	0.080	0.050	0.040	0.060	0.030	0.080

TABLE A1.13 (cont.)

Date	20.6.1978				4.7.1978			
STATION	1	2	3	4	1	2	3	4
Current velocity cm sec^{-1}	-	-	-	-	-	-	-	-
Temperature ^{o}C	12.7	13.9	13.4	13.9	11.2	11.8	11.6	11.6
Suspended solids	11.50	15.75	16.25	14.50	53.50	59.50	163.00	152.00
Chlorides	29.0	58.0	60.0	57.0	22.0	38.0	31.0	28.0
Alkalinity	130.0	155.0	155.0	155.0	85.0	100.0	100.0	100.0
Total hardness	220.0	252.0	278.0	278.0	166.0	182.0	180.0	192.0
Ca hardness	168.0	194.0	188.0	192.0	130.0	138.0	140.0	148.0
Mg hardness	52.0	58.0	90.0	86.0	36.0	44.0	40.0	44.0
pH	7.4	7.3	7.3	7.3	7.3	7.2	7.2	7.2
Dissolved oxygen	9.8	8.7	8.4	7.9	9.4	8.6	8.8	8.5
BOD	2.6	4.3	4.2	4.9	4.7	7.1	8.7	8.4
Ammonia	0.10	0.20	0.30	0.40	0.20	0.30	0.70	0.50
Nitrates	3.70	6.00	7.70	8.50	3.10	4.10	4.00	4.00
Phosphates	0.80	3.20	3.60	3.60	0.80	1.90	1.60	1.60
Cadmium	0.001	0.002	0.002	0.002	0.000	0.001	0.001	0.002
Chromium	0.000	0.060	0.100	0.080	0.010	0.010	0.010	0.010
Copper	0.004	0.018	0.026	0.056	0.010	0.014	0.024	0.028
Lead	0.010	0.020	0.020	0.020	0.020	0.020	0.040	0.040
Nickel	0.010	0.015	0.020	0.020	0.015	0.015	0.020	0.020
Zinc	0.030	0.070	0.060	0.070	0.040	0.060	0.110	0.130

APPENDIX 2 BIOLOGICAL DATA

Abbreviations and Notes

N/Nat. - Natural substrata

R - Riffle

P - Pool

S - Polythene Strip

Natural substrata (see Section 4.3.2.1)

Abundance ratings 5- abundant

4- common

3- frequent

2- occasional

1- rare

Some taxa are reported in terms of estimated percentage cover

Artificial substrata (see Section 4.3.2.2)

Results reported as numbers of cells per unit area:

Table A2.1- nos. cm^{-2}

Other Tables- nos. $cm^{-2} \times 10^{-3}$

Some taxa are recorded as present (P) only

General

Where samples were taken (from natural substrata) on the first visit to a particular sampling station, the appropriate table is noted "First Visit". In many cases, the purpose of the first visit was solely to set the artificial substrata in position, no samples being taken until the second visit. In these cases, the first data table presented for the station refers to this second visit, the date of the first visit being given in brackets.

Nomenclature follows Whitton et al.(1978). In Table A2.1, the dimensions of the three unidentified Navicula species (length x maximum valve breadth) were: sp. 1 (21 x 6µ) sp.2 (47x11µ) sp. 3 (45x10µ)

The following abbreviations are also employed:

a) Reasons for not sampling at a particular site-

NP- site not present or available

NA- site not accessible on day of sampling

b) Apparent reasons for absence of organisms-

E- emersion of artificial substrata

F- fouling or shading out of artificial substrata

L- loss of artificial substrata

I- inaccessibility of artificial substrata

U- unknown, presumably natural causes, e.g. scouring

TABLE A2.1

RIVER TEAN

STATION T1R	15 DAYS				28 DAYS			
	NAT.	TILE	PLATE	STRIP	NAT.	TILE	PLATE	STRIP
Filamentous bacteria	4				5			
Oscillatoria sp.	2				1			
Cladophora glomerata	2				2			
Stigeoclonium tenue								
Ulothrix sp.		1						
Vaucheria sp.					2			
Batrachospermum sp.	4				1			
Meloseira varians	2	533	100	1200	3	556	800	300
Cyclotella meneghiniana								
Rhoicosphenia curvata	4	1066	1250	1600	2	1889	2200	3300
Gomphonema parvulum		1378	750	1900	2	444	800	1800
Diatoma vulgare	3	444	300	400	2	111	800	450
Synedra ulna	2	267	100		2	222	200	300
Fragilaria capucina	2				2		200	
Amphora ovalis	1	44						
Achnanthes linearis	2	33333	1800	3400		5889	7200	4050
Cymbella prostrata	2	889	400	600	2	1000	600	900
Caloneis amphisbaena								
Cymatopleura solea								
Cyrosigma attenuatum								
Surirella ovata		533		200	1			
Cocconeis placentula		311	350	1000	1	6111	11600	10800
Navicula sp.1	2	1377	850	1700	2	778	1400	450
Navicula sp.2	2	978	200	700	1	667	400	450
Navicula sp.3	2	225		100	1		200	
Nitzschia palea	2	44667	4100	9400	1	1000	5400	4500
Nitzschia acicularis	1	3511	850	1000	1			
Nitzschia linearis		489	600	100	1			
Nitzschia sublinearis				200	1			
Nitzschia sigmoidea						111		
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.1 (cont) RIVER TEAN

STATION T1P	15 DAYS				28 DAYS			
	MAT.	TILE	PLATE	STRIP	MAT.	TILE	PLATE	STRIP
Filamentous bacteria		NOT USED				NOT USED		
Oscillatoria sp.	1							
Cladophora glomerata	2				1			
Stigeoclonium tenue								
Ulothrix sp.								
Vaucheria sp.								
Batrachospermum sp.								
Melosira varians	2		700	200	3		3300	4500
Cyclotella meneghiniana								
Rhoicosphenia curvata	2		1500 350	400			2400	2400
Gomphonema parvulum			900 300	800			1200	300
Diatoma vulgare	2		150	150			300	
Synedra ulna	2			350	1		750	300
Fragilaria capucina	2		100	50	2		150	150
Amphora ovalis								
Achnanthes linearis			3300 200	2950			5100	3900
Cymbella prostrata			1000	550			450	1800
Caloneis amphisbaena	1							
Cymatopleura solea	1		100				150	150
Gyrosigma attenuatum	1		100		2			
Surirella ovata								
Cocconeis placentula			2100 950	550			8550	2700
Navicula sp.1	1		1800 400	350	3		1200	3150
Navicula sp.2	1		600 50	200	1		300	
Navicula sp.3	1		100	100	1		300	150
Nitzschia palea	2		6300 100	1850	1		3150	3750
Nitzschia acicularis	2		2600	800	4		900	1050
Nitzschia linearis	2		7700 950	750	2		300	150
Nitzschia sublinearis			200		2			300
Nitzschia sigmoidea	2			50	3		150	150
Nitzschia sigma			100					
Nitzschia amphibia								300

TABLE A2.2 (cont.) RIVER TEAN

STATION T2R	15 DAYS				28 DAYS			
	NAT.	TILE	PLATE	STRIP	NAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.	2							
Cladophora glomerata	4				5			
Stigeoclonium tenue								
Ulothrix sp.								
Vaucheria sp.								
Batrachospermum sp.	4				3			
Melosira varians								
Cyclotella meneghiniana								
Rhoicosphenia curvata	2							
Gomphonema parvulum								
Diatoma vulgare								
Synedra ulna	1							
Fragilaria capucina								
Amphora ovalis								
Achnanthes linearis								
Cymbella prostrata								
Caloneis amphisbaena								
Cymatopleura solea								
Gyrosigma attenuatum								
Surirella ovata								
Cocconeis placentula								
Navicula sp.1					1			
Navicula sp.2	1				1			
Navicula sp.3								
Nitzschia palea								
Nitzschia acicularis								
Nitzschia linearis	1							
Nitzschia sublinearis								
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.1 (cont.)

RIVER TEAN

STATION T2P	15 DAYS				28 DAYS			
	MAT.	TILE	PLATE	SCRIP	MAT.	TILE	PLATE	SCRIP
Filamentous bacteria		NOT USED				NOT USED		
Oscillatoria sp.	2							
Cladophora glomerata	5				5			
Stigeoclonium tenue								
Ulothrix sp.								
Vaucheria sp.								
Batrachospermum sp.								
Melosira varians								
Cyclotella meneghiniana								
Rhoicosphenia curvata								
Gomphonema parvulum								
Diatoma vulgare	1							
Synedra ulna								
Fragilaria capucina								
Amphora ovalis								
Achnanthes linearis								
Cymbella prostrata								
Caloneis amphisbaena								
Cymatopleura solea	1							
Gyrosigma attenuatum								
Surirella ovata								
Cocconeis placentula								
Navicula sp.1								
Navicula sp.2								
Navicula sp.3								
Nitzschia palea								
Nitzschia acicularis								
Nitzschia linearis								
Nitzschia sublinearis								
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.1 (cont.)

RIVER TEAN

STATION AR	15 DAYS				28 DAYS			
	NAT.	TILE	PLATE	STRIP	NAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.								
Cladophora glomerata								
Stigeoclonium tenue								
Ulothrix sp.								
Vaucheria sp.	4				5			
Batrachospermum sp.				3				
Melosira varians	4	667		700	1			
Cyclotella meneghiniana	1							
Rhoicosphenia curvata	4	2333		1500	1	1333		4200
Gomphonema parvulum	2	2667		3700	1	889		1500
Diatoma vulgare	2	556		800	1			
Synedra ulna	4			1100				300
Fragilaria capucina	2	556		200				
Amphora ovalis				100				
Achnanthes linearis	1	5111		4800		75556		4200
Cymbella prostrata	1	1889		1000		2222		150
Caloneis amphisbaena								
Cymatopleura solea		222						150
Gyrosigma attenuatum								
Surirella ovata	1	1444		500		178		
Cocconeis placentula				700		444		9000
Navicula sp.1	4	3556		1900	1	1422		300
Navicula sp.2	2	1778		300		444		450
Navicula sp.3	2					178		
Nitzschia palea	1	166444		199500				1950
Nitzschia acicularis	1	18889						
Nitzschia linearis	4	3222		200				
Nitzschia sublinearis	1			200				
Nitzschia sigmoidea								150
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.1 (cont.)

RIVER TEAN

STATION - A25	15 DAYS				28 DAYS			
	NAT.	TILE	PLATE	STRIP	NAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.								
Cladophora glomerata					2			
Stigeoclonium tenue						3		
Ulothrix sp.								
Vaucheria sp.								
Batrachospermum sp.								
Melosira varians	4	444		600	1	267		
Cyclotella meneghiniana								
Rhoicosphenia curvata		800		500	1	1467		600
Gomphonema parvulum	2	8089		3100	1	467		4050
Diatoma vulgare		89		100				
Synedra ulna	3	89		4600	1			1950
Fragilaria capucina		44		200				
Amphora ovalis								
Achnanthes linearis	3	5867				267		300
Cymbella prostrata	2	178		1100		400		600
Caloneis amphisbaena								
Cymatopleura solea								
Gyrosigma attenuatum								150
Surirella ovata	2	44		1200				
Cocconeis placentula				200		200		450
Navicula sp.1	4			400	1	667		300
Navicula sp.2	3	267		200	1	267		300
Navicula sp.3								
Nitzschia palea	3	23644		218000		800		1500
Nitzschia acicularis								
Nitzschia linearis	3	44		900				
Nitzschia sublinearis				200				
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.1 (cont.)

RIVER TEAN

STATION A50	15 DAYS				28 DAYS			
	NAT.	TILE	PLATE	STRIP	NAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.								
Cladophora glomerata	4				1			
Stigeoclonium tenue		2				3		
Ulothrix sp.	3	3						
Vaucheria sp.								
Batrachospermum sp.					1			
Melosira varians	3	2756			4	2222		
Cyclotella meneghiniana	1							
Rhoicosphenia curvata	1	1422			1			
Gomphonema parvulum	4	21956			2	14333		
Diatoma vulgare		533						
Synedra ulna	2	2844			2	778		
Fragilaria capucina	3	444				444		
Amphora ovalis								
Achnanthes linearis		7912				4333		
Cymbella prostrata	1	150			1	333		
Caloneis amphisbaena								
Cymatopleura solea								
Gyrosigma attenuatum								
Surirella ovata	1							
Cocconeis placentula		355						
Navicula sp.1	4	89			1	1111		
Navicula sp.2	2	889				778		
Navicula sp.3								
Nitzschia palea	3	38578			1	1889		
Nitzschia acicularis	2	178						
Nitzschia linearis	3	267			1			
Nitzschia sublinearis								
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.1 (cont.)

RIVER TEAN

STATION A75	15 DAYS				28 DAYS			
	NAT.	TILE	PLATE	STRIP	NAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.								
Cladophora glomerata					4			
Stigeoclonium tenue	4	4				4		
Ulothrix sp.	3	3						
Vaucheria sp.								
Batrachospermum sp.					3			
Melosira varians	4	1333			2	2667		
Cyclotella meneghiniana								
Rhoicosphenia curvata		667						750
Gomphonema parvulum	2	13933			3	12111		8850
Diatoma vulgare		200						
Synedra ulna	2	5133			3	3444		300
Fragilaria capucina		67				333		
Amphora ovalis								
Achnanthes linearis		800				4444		
Cymbella prostrata		400						
Caloneis amphisbaena								
Cymatopleura solea								
Gyrosigma attenuatum								
Surirella ovata								
Cocconeis placentula								
Navicula sp.1	2	333						
Navicula sp.2		200						
Navicula sp.3								
Nitzschia palea	2	3933				1444		1800
Nitzschia acicularis								
Nitzschia linearis	2	200						300
Nitzschia sublinearis								
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia						1000		1200

TABLE A2.1 (cont.)

RIVER TEAN

STATION A100	15 DAYS				28 DAYS			
	MAT.	TILE	PLATE	STRIP	MAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.								
Cladophora glomerata								
Stigeoclonium tenue	4	4			3	3	3	5
Ulothrix sp.	3							
Vaucheria sp.								
Batrachospermum sp.								
Melosira varians	4						800	
Cyclotella meneghiniana								
Rhoicosphenia curvata								
Gomphonema parvulum		64889				105555	12900	3300
Diatoma vulgare								
Synedra ulna	3	27733			2	42444	800	1100
Fragilaria capucina								
Amphora ovalis								
Achnanthes linearis								
Cymbella prostrata								
Caloneis amphisbaena								
Cymatopleura solea								
Gyrosigma attenuatum								
Surirella ovata								
Cocconeis placentula								
Navicula sp.1								
Navicula sp.2								
Navicula sp.3								
Nitzschia palea		7822						
Nitzschia acicularis								
Nitzschia linearis	2							
Nitzschia sublinearis								
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia								300

TABLE A2.1 (cont.) RIVER TEAN

STATION ER	15 DAYS				28 DAYS			
	NAT.	TILE	PLATE	STRIP	NAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.	2							
Cladophora glomerata	3							
Stigeoclonium tenue								
Ulothrix sp.								
Vaucheria sp.					4			
Batrachospermum sp.								
Melosira varians	2				1			
Cyclotella meneghiniana								
Rhoicosphenia curvata	4	756			3			
Gomphonema parvulum	1	89						
Diatoma vulgare	2	89			1			
Synedra ulna	2	267						
Fragilaria capucina	2	44						
Amphora ovalis								
Achnanthes linearis	3							
Cymbella prostrata	2							
Caloneis amphisbaena								
Cymatopleura solea								
Gyrosigma attenuatum								
Surirella ovata								
Cocconeis placentula								
Navicula sp.1	2	44						
Navicula sp.2	2							
Navicula sp.3	2	44						
Nitzschia palea		1911						
Nitzschia acicularis								
Nitzschia linearis	2	89						
Nitzschia sublinearis								
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.1 (cont)

RIVER TEAN

STATION E50	15 DAYS				28 DAYS			
	MAT.	TILE	PLATE	STRIP	MAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.	1							
Cladophora glomerata	4				4			
Stigeoclonium tenue								
Ulothrix sp.								
Vaucheria sp.								
Batrachospermum sp.								
Melosira varians								
Cyclotella meneghiniana								
Rhoicosphenia curvata	1							
Gomphonema parvulum	1							
Diatoma vulgare								
Synedra ulna	1							
Fragilaria capucina								
Amphora ovalis								
Achnanthes linearis								
Cymbella prostrata								
Caloneis amphisbaena								
Cymatopleura solea								
Gyrosigma attenuatum								
Surirella ovata								
Cocconeis placentula								
Navicula sp.1								
Navicula sp.2								
Navicula sp.3								
Nitzschia palea	1							
Nitzschia acicularis								
Nitzschia linearis	1							
Nitzschia sublinearis								
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.1 (cont.) RIVER TEAN

STATION E75	15 DAYS				28 DAYS			
	NAT.	TILE	PLATE	STRIP	NAT.	TILE	PLATE	STRIP
Filamentous bacteria								
Oscillatoria sp.	1							
Cladophora glomerata	5				4			
Stigeoclonium tenue								
Ulothrix sp.								
Vaucheria sp.								
Batrachospermum sp.								
Melosira varians								
Cyclotella meneghiniana								
Rhoicosphenia curvata								
Gomphonema parvulum	2							
Diatoma vulgare	2							
Synedra ulna	2							
Fragilaria capucina								
Amphora ovalis								
Achnanthes linearis								
Cymbella prostrata								
Caloneis amphisbaena								
Cymatopleura solea								
Gyrosigma attenuatum								
Surirella ovata								
Cocconeis placentula								
Navicula sp.1	2							
Navicula sp.2								
Navicula sp.3								
Nitzschia palea	2							
Nitzschia acicularis								
Nitzschia linearis	2							
Nitzschia sublinearis								
Nitzschia sigmoidea								
Nitzschia sigma								
Nitzschia amphibia								

TABLE A2.2

RIVER WEAVER — DATE 29.3.1977 (First Visit)

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis							NP	1						U					NP	U				
Caloneis amphisbaena								1																
Cymatopleura solea								1																
Diatoma vulgare	1												1											
Gomphonema olivaceum	1												3											
parvulum	1																							
Meridion circulare													2											
Navicula spp.	2	1						3					5											
Nitzschia palea								2					3											
Sigma								1																
Sigmoidea		1																						
Pinnularia sp.								1																
Synedra ulna	2	1						2					4											
Closterium sp.								1																

TABLE 42.2 (cont.)

RIVER WEAVER — DATE 26.4.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis		1					NP	1											NP					
Caloneis amphisbaena		1						1																
Cymatopleura solea																				1				
Cymbella ventricosa			·2	·2	0				·4	0	·1				·3	0	·1				·4	2·8	·2	
Diatoma vulgare			·8	·9	·7				1·1	·6	·6		2		·1	·2	·6				·7	·3	·3	
Fragilaria capucina			0	0	·2				·1	0	·2				·4	·2	·1				0	·2	0	
Gomphonema olivaceum			3·9	3·1	1·9				·9	1·4	2·2		3		2·1	·8	·9				1·2	1·9	·6	
Melosira varians													1											
Navicula spp.	1	1	65·4	34·2	23·6			1	4·9	3·4	7·0		4	2	15·4	11·3	8·1			1	3·7	14·6	2·5	
Nitzschia acicularis													1	2						1				
linearis													1	1										
palea			·1	·1	·3				·3	·2	·1		1	2	·4	·5	·4			1	·3	·1	·3	
Synedra ulna	1	1	8·8	6·1	2·8			1	·8	·9	2·1		4		5·0	5·2	3·9				1·8	3·2	1·9	
Oscillatoria limosa		2																						
Scenedesmus quadricauda			0	·3	·2				0	0	·2				·2	·1	·3				0	·3	·1	

TABLE 42.2 (cont.)

RIVER WEAVER DATE 24.5.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis		2	E	E	E		NP	2						U	E	E	E		NP	U	E	E	E	
Caloneis amphisbaena		2						2																
Cymatopleura solea									·3	·4	0													
Diatoma vulgare	2												2											
Gomphonema olivaceum	3								1·7	1·3	1·1		2											
Melosira varians													2											
Navicula spp.	3	4						2	12·6	9·5	16·8		4											
Nitzschia acicularis								4					1											
linearis		2											1											
palea								4					3											
sigma		1																						
Synedra ulna	5								·3	0	0		4											
Oscillatoria limosa		2						4																
Enteromorpha intestinalis	5%																							
Cladophora glomerata	20%																							
Vaucheria sp.	5%																							

TABLE A2.2 (cont.)

RIVER WEAVER — DATE 21.6.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis			F	F	F		NP	1											NP		U	U	U	
Caloneis amphisbaena		2						1																
Cocconeis placentula	1																							
Cymatopleura solea								1	0	·2	0				0	0	0							
Gomphonema olivaceum	1																							
parvulum									0	0	0				·2	·1	0							
Gyrosigma attenuatum	1	2											1											
Melosira varians	1																							
Navicula spp.	1	3						2	1·8	2·6	2·2		1		0	0	0			1				
Nitzschia palea		1						1	0	0	0				1·9	2·5	·3			1				
Rhoicosphenia curvata	1								0	0	·1		2		·3	0	0							
Synedra ulna													1							1				
Cladophora glomerata	40%	40%						10%					15%	5%										
Closterium sp.		1						1												2				
Palmelloid green									P	P	P				P	P	P							

TABLE A2.2 (cont.)

RIVER WEAVER — DATE 19.7.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			·1	·1	·2		NP		0	·4	·6				F	F	F		NP	U	4·1	3·8	1·9	
Cocconeis placentula	2	2	5·1	4·3	6·4				4·2	3·6	6·7										2·6	2·4	1·1	
Cymbella ventricosa			·1	0	·3				0	0	0										0	0	0	
Diatoma vulgare	2	2																						
Fragilaria capucina	2																							
Gomphonema olivaceum	2	1																						
parvulum									·3	·6	1·3										·2	0	0	
Melosira varians	4	4	8·2	2·4	5·2				0	0	0										·3	0	0	
Navicula spp.	3	2	2·3	·9	2·6			1	0	0	0										0	0	0	
Nitzschia acicularis								1																
palea	1	2	·2	0	·3			1	·2	0	·2										0	0	0	
Rhoicosphenia curvata	4	4	6·7	3·7	4·4				2·1	2·3	1·8		2								0	0	0	
Synedra ulna	2	2	·1	0	·1				0	0	0		2								0	0	0	
Oscillatoria limosa	1	2																						
Cladophora glomerata	30%	30%											80%	10%										
Closterium sp.	1	1											2											
Enteromorpha intestinalis	20%	5%						5%																
Pediastrum duplex													2											
Scenedesmus quadricauda													3											
Palmelloid green			P	P	P				P	P	P		2								P	P	P	

TABLE 42.2 (cont.)

RIVER WEAVER — DATE 16.8.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			·6	·3	·1		NP		0	·1	0				F	F	F		NP		·1	·2	0	
Amphora ovalis			·1	·1	0				·1	0	0										0	0	0	
Caloneis amphisbaena								1																
Cocconeis placentula	2	3	4·3	8·1	2·8				4·5	7·6	14·6		1								0	0	·2	
Cyclotella kautzingiana			0	0	0				0	0	0		5	4							·4	·9	0	
Cymatopleura solea			0	0	0				0	0	0		1								0	·1	·1	
Cymbella lanceolata	1	1	·1	0	0				0	0	0										0	0	0	
ventricosa	3	1	2·3	1·1	·1				0	0	0										0	0	0	
Diatoma vulgare		2	0	0	0				0	·2	·2										0	0	0	
Gomphonema parvulum	1		·8	·2	·4				0	·2	·6		3	3							·2	1·8	0	
Gyrosigma attenuatum		1	0	0	0			1	0	0	0										0	·1	·1	
Melosira varians	3	3	14·9	4·5	1·6				·2	·1	0		2								·2	1·4	0	
Navicula spp.	2	1	·2	·2	0			1	·9	0	·6		2							1	·5	·8	0	
Nitzschia acicularis													2	2										
linearis		1																						
palea	3	1	0	0	0				1·2	·2	·6										·3	0	0	
sigmoidea		1	0	0	0				0	·1	0										0	·8	·1	
Rhoicosphenia curvata	4	5	8·4	11·3	1·3				1·4	·2	0		3	3							0	0	·1	
Synedra ulna	2	2	·3	·2	·1				1·5	1·2	0		4	4							0	·3	0	
Oscillatoria limosa	1	1											1											
Cladophora glomerata	5%	60%											70%	10%										
Closterium sp.	2	3	·1	0	0				0	0	0		2	1							0	0	0	
Enteromorpha intestinalis	5%	10%																						
Oedogonium sp.	1																							
Pediastrum duplex	1																							
Scenedesmus quadricauda	2	1	·2	·1	0				0	0	0		1								0	0	0	
Stigeoclonium tenue			P	P	P				—	—	P										—	—	—	
Palmelloid Green			P	P	P				P	P	P										0	0	0	
Carchesium polypinum			—	—	—				P	P	P										—	—	—	

TABLE 42.2 (cont.)

RIVER WEAVER — DATE 15.9.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			0	0	0		NP		0	0	0				F	F	3.6		NP	U	U	U	0	
Amphora ovalis			.3	0	.4				.1	.2	0						0						.1	
Caloneis amphisbaena			0	0	.1				0	0	0		1				0						0	
Cocconeis placentula			12.6	9.4	7.2				.7	.4	1.3		1				0						0	
Cyclotella kuetzingiana													4											
Cymatopleura elliptica			.1	.1	.1				.1	0	0						0						0	
solea			.1	0	.1				0	0	0						0						0	
Cymbella venticosa			1.4	.5	.4				0	0	0						0						0	
Diatoma vulgare													1											
Fragilaria capucina			.1	0	0				0	0	0						0						0	
Gomphonema parvulum			.8	1.0	.4				0	0	0		2				3.2						0	
Gyrosigma attenuatum													1											
Melosira varians	1		.3	1.8	3.7				0	0	0		1				0						0	
Navicula spp.		1	4.2	3.2	2.1				.1	.4	.3		1				0						0	
Nitzschia acicularis													1											
linearis		1	.1	0	0				0	0	0						0						0	
palea			.5	.8	.3			1	0	0	0		2				2.6						0	
sigmoidea	1		.1	.1	0				0	0	0		1				0						.3	
Rhoicosphenia curvata			3.8	2.8	1.5				0	0	0		4				0						0	
Synedra ulna			1.1	1.2	.6				.1	0	0		4				0						.2	
Chamaesiphon sp.			1.7	.8	.1				0	0	0						0						0	
Oscillatoria limosa													1											
Cladophora glomerata	5%	5%											50%	5%										
Closterium sp.													2											
Scenedesmus quadricauda			.1	0	0				0	0	0						0						0	
Spirogyra sp.													1											
Stigeoclonium tenue			–	–	–				–	–	–						P						–	
Palmelloid green			P	P	P				–	–	–						P						–	
Carchesium polypinum			–	–	–				P	P	P						–						–	

TABLE A2.2 (cont.)

RIVER WEAVER — DATE 11.10.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			0	·2	0		NP		0	0	0				F	F	0		NP		0	0	0	
Amphora ovalis	3		0	0	0			1	·1	0	0						0			2	0	·1	·2	
Coloneis amphisbaena	1	1																						
Cocconeis placentula			6·9	9·7	4·3				·2	3·7	2·2						·1				0	0	0	
Cyclotella kuetzingiana													1											
Cymatopleura elliptica	2																							
solea	2																			1				
Cymbella ventricosa			1·2	1·4	1·0				0	·1	0						0				0	0	0	
Diatoma vulgare													2											
Gomphonema parvulum			3·2	2·4	1·3				0	0	·1		3				·1				0	0	0	
Gyrosigma attenuatum	1	1	0	·1	0				·1	0	0						0				0	0	0	
Melosira varians			·3	·2	0				·3	·2	·2		1				0				·3	0	·4	
Navicula spp.	1		14·2	5·5	3·4			1	·1	·8	1·0		2				·1			1	0	0	·5	
Nitzschia linearis	2		·2	1·8	1·4				0	0	·1		2				0			1	·3	·4	0	
palea			5·3	3·2	·9			1	0	·2	·4		3				0			1	0	0	0	
sigmoidea	4		·1	·3	·7				·1	0	·1		1				0			1	0	·1	·1	
sublinearis			0	0	0				0	0	·7						0				0	0	·3	
Rhoicosphenia curvata			4·3	·7	·2				0	0	0		3				·6				0	0	·1	
Surirella ovata													1											
Synedra ulna			1·0	·1	0				0	0	0		2				0				0	·3	·4	
Oscillatoria tenuis													1							2				
Characium sp.													1											
Cladophora glomerata													30%	5%										
Scenedesmus quadricauda			0	·1	0				–	–	·3		1				–				–	–	·2	
Stigeoclonium tenue													1											
Palmelloid green			–	–	–				–	–	–						P				–	–	–	

TABLE A2.2 (cont.)

RIVER WEAVER — DATE 11.11.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			0	·4	·2		NP		0	0	0		NA		0	0	0		NP		U	0	0	
Amphora ovalis	1	1	0	0	0			3	0	0	·2				0	0	0			1		0	0	
Cocconeis amphisbaena		2						1																
Cocconeis placentula			·8	1·6	2·9				1·8	0	0				1·9	2·3	0					0	0	
Cymatopleura elliptica	1	1	0	·1	0			1	0	0	0				0	0	0					0	0	
solea		1	0	·1	0			1	0	0	0				0	0	0			1		0	0	
Cymbella cistula			0	·7	·6				0	0	0				0	0	0					0	0	
lanceolata			0	·2	·1				·3	0	0				0	0	0					0	0	
Gyrosigma attenuatum	1	2	0	·2	·1			3	0	0	0			1	0	0	0			1		0	0	
Gomphonema olivaceum			0	·1	0																			
parvulum			0	1·2	·4				·2	·3	·1				5·4	4·9	2·1					0	0	
Melosira varians	3	2	0	·2	0			1	0	0	0				0	0	0			1		0	·4	
Navicula spp.	2	3	·2	2·7	5·3			3	0	·1	0				·2	·1	0			1		·3	·5	
Nitzschia linearis	2	2	·1	3·4	1·5			3	0	0	·4			1	0	0	0			1		0	0	
palea		2	0	1·8	1·3			2	1·2	1·6	0				0	0	0			1		0	0	
recta			0	·3	0				0	0	0				0	0	0					0	0	
sigma			0	·2	0				0	0	0				0	0	0					0	0	
sigmoidea	2	3	·2	3·8	·9			2	0	0	·1				0	0	0			1		0	0	
sublinearis		1	0	·3	·1			1	0	0	0				0	0	0			1		0	0	
Rhoicosphenia curvata	1		0	1·8	1·2				·5	·2	·2				0	0	0					0	0	
Synedra ulna	1		0	·2	0				0	0	0				0	0	0					0	0	
Merismopedia glauca								1																
Oscillatoria sp.	1	1												1						1				
Closterium aciculare								1																
Closterium sp.	1	1																		1				
Scenedesmus quadricauda			0	·2	0				0	0	0				0	0	0					0	0	
Palmelloid green															P	P	P							
Euglenoid flagellates																				2				
Carchesium polypinum									P	P	P													

TABLE 42.2 (cont.)

RIVER WEAVER — DATE 6.12.1977

STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis	1	3	0	0	0		NP	U	.6	.2	0		1	U	0	0	0		NP	U	U	U	U	
Caloneis amphisbaena		1																						
Cymatopleura elliptica			0	.1	0				0	0	0				0	0	0							
solea			.1	0	0				0	.1	0		1		0	0	0							
Cymbella cistula			0	.1	0				0	0	0		1		0	0	0							
prostrata			0	0	0				0	0	0				.1	.1	0							
Diatoma vulgare			0	0	0				.4	0	0		3		0	0	0							
Gomphonema olivaceum													3											
parvulum			.2	.1	1.2				0	0	0		2		0	0	0							
Gyrosigma attenuatum	1		.1	0	0				0	0	.1		1		0	0	0							
Melosira varians			.6	.2	0				.4	.2	0		2		0	0	0							
Navicula spp.	1		1.2	3.4	2.1				1.7	1.1	.2		4		.2	.1	.1							
Nitzschia linearis			.3	.5	0				.1	0	0		2		0	0	0							
palea			.2	0	.2				0	0	0		2		.1	.1	0							
sigma			0	0	0				0	0	0				0	0	.1							
sigmoidea	1	2	.5	.9	.3				.4	0	0		1		0	0	0							
Pinnularia sp.													1											
Rhaicosphenia curvata													2											
Surirella ovata													1											
Synedra ulna	1												2											
Oscillatoria tenuis		1																						
Cladophora glomerata													5%											
Closterium acicular		1																						
Scenedesmus quadricauda	1												2											
Stigeoclonium tenue													1											
Vaucheria sp.													2											
Rhodochorton violaceum													1											

TABLE 42.3

RIVER TRENT	DATE 30.5.1977 (2.5.1977)												DATE 1.6.1977 (6.5.1977)											
STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cymbella prostrata		NA	F	F	F			NA	F	F	F		NP	U	·6	·7	·7			NA	L	L	L	
Diatoma vulgare	5						3																	
Gomphonema parvulum							1								0	1·8	0							
Melosira varians	2						2												2					
Navicula spp.	2						1								0	3·6	3·7		1					
Nitzschia palea															0	5·2	10·3		2					
Rhoicosphenia curvata	3						1								0	0	·4		2					
Synedra ulna	2						4												1					
Cladophora glomerata	10%																		5%					
Enteromorpha intestinalis	10%																							
Stigeoclonium tenue							10%								P	P	P							

TABLE 42.3 (cont.)

RIVER TRENT	DATE 27·6·1977												DATE 29·6·1977											
STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cocconeis placentula		NA	F	F					L	F			NP		F	F	1·8		NA	NA	I	I	I	
Cymbella prostrata														2										
Diatoma vulgare	5				·1		2	1																
Gomphonema olivaceum							1	1																
parvulum	2						3	2			·4			1			2·9							
Melosira varians	3				·3		2	3						2			·2							
Navicula spp.	2						2	2						1										
Nitzschia acicularis								3																
linearis					·1																			
palea	2				·8		4	3						2										
Sigma	1																							
sigmoidea								1																
Sublinearis							1	1																
Rhoicosphenia curvata	4				·6		1	1			·1			1			·3							
Synedra ulna	2						2	3						2			·9							
Cladophora glomerata	5%							10%						5%										
Enteromorpha intestinalis	50%																							
Scenedesmus quadricauda							1																	
Stigeoclonium tenue							10%				P													
Palmelloid green					P																			

TABLE 42.3 (cont.)

RIVER TRENT	DATE 26.7.1977												DATE 28.7.1977											
STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Caloneis amphisbaena		NA	F	F				1	F	F			NP							NA				
Cocconeis placentula	1				2.9						1.2			1	11.8	6.8	3.6				5.2	0	0	
Cymatopleura solea	1							1																
Diatoma vulgare	2						1							1					1					
Gomphonema olivaceum								1																
parvulum							1				12.3													
Melosira varians	2						1	2						1					3					
Navicula spp.								1																
Nitzschia linearis								2																
palea							2	1			.9			1	2.6	1.3	1.4		2		.3	0	0	
sigmoidea								1																
Rhoicosphenia curvata	4				3.2		3				9.8			1	1.8	2.4	1.2		2		.9	.3	2.8	
Synedra ulna							1	1						1	.1	0	0		1					
Characium sp.															0	1.3	2.3							
Cladophora glomerata	80%						5%							10%	P	P	P		30%					
Enteromorpha intestinalis	10%							5%																
Scenedesmus quadricauda							1												1					
Palmelloid green					P						P				P	P	P				P	P	P	

TABLE 42.3 (cont)

RIVER TRENT	DATE 22.8.1977												DATE 26.8.1977											
STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cocconeis placentula	2	NA	.8	0	.9		1	1	F	F	F		NP	NA	I	I	I		NA	NA	I	I	I	
Diatoma vulgare								1																
Fragilaria capucina								1																
Melosira varians	2						1	1																
Navicula spp.	1																							
Nitzschia palea	1																							
Rhoicosphenia curvata	3		3.1	1.0	1.6		1	2																
Cladophora glomerata	40%						15%	5%																
Palmelloid green	P						P	P																

TABLE A2.3 (cont)

RIVER TRENT	DATE 20.9.1977												DATE 23.9.1977											
STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Asterionella formosa	2	NA							L	L	L		NP		L	L	L			NA	F	F	F	
Bacillaria paradoxa														2										
Cocconeis placentula	1		0	3.5	4.6																			
Cyclotella kautzingiana	2						1	1																
meneghiniana																			2					
Diatoma vulgare	4						4	1											1					
Fragilaria capucina	1						1	1																
Gomphonema olivaceum	1						1	2																
parvulum							2	2																
Melosira varians	1						2	3						2					2					
Navicula spp.	2						1	2											2					
Nitzschia acicularis	1							1																
palea	2						2	3						1										
sigmoidea	1																							
Rhoicosphenia curvata	2		.1	.2	.2		3	2											2					
Surirella ovata	1							1																
Synedra acus	2																		1					
ulna	3						4	4											2					
Oscillatoria sp.	1																							
Cladophora glomerata	80%						35%	5%						5%					15%					
Enteromorpha intestinalis	10%																							
Scenedesmus quadricauda	1						1	1																
Stigeoclonium tenue								5%																
Ulothrix zonata								2																
Palmelloid green					P																			

TABLE A2.3 (cont.)

RIVER TRENT	DATE 17.10.1977												DATE 21.10.1977											
STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.		NA	F	F					F	F	F		NP							NA	•1	0	0	
Bacillaria paradoxa														2										
Cocconeis placentula	2						1	2						2	4·7	2·6	1·9							
Gymnatopleura solea														1							0	0	•1	
Cymbella prostrata														1										
Diatoma vulgare	1						2	2																
Fragilaria capucina														1					1					
Gomphonema augur														1										
olivaceum														1										
parvulum	1						3	2						1	4·3	1·6	2·2							
Gyrosigma attenuatum																					•1	0	0	
Melosira varians	2						3	2						3					2		13·4	•8	9·4	
Navicula Spp.	3						2	2						2					4		•5	1·6	2·9	
Nitzschia linearis															•1	0	0							
palea	1						3	2											1		•9	1·8	1·3	
sigmoidea																					0	0	•1	
Rhoicosphenia curvata	4				•2		2	2						2	2·1	•3	0		3		1·2	4·7	1·2	
Synedra ulna	1						3	2						1					2					
Characium sp.														1	0	•1	0							
Cladophora glomerata	15%						5%	5%						10%					5%					
Closterium sp.														1										
Enteromorpha intestinalis	15%						5%																	
Scenedesmus quadricauda							1	1						1										
Stigeoclonium tenue							5%	5%							P	P	P							
Palmelloid green															P	P	P				P	P	P	

TABLE A2.3 (cont.)

RIVER TRENT	DATE 15.11.1977												DATE 18.11.1977											
STATION	1						2						3						4					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Gomphonema olivaceum	1	NA	F	F	F		NA	NA	L	L	L		NP	NA	I	I	I		NA	NA	I	I	I	
Melosira varians	2																							
Navicula spp.	3																							
Nitzschia acicularis	1																							
palea	1																							
Rhoicosphenia curvata	1																							
Surirella ovata	1																							
Cladophora glomerata	5%																							

TABLE 42.4

RIVER TAME	DATE 30.5.1977 (2.5.1977)												DATE 27.6.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Diatoma vulgare		NA	F	F			2	NA	F	2.4	0				F	F	F			NA	F	F	F	
Gomphonema olivaceum													1											
parvulum	2				24.3		2			7.1	3.4		3						1					
Navicula sp.							1												1					
Nitzschia palea					5.6					.6	.3		4						1					
Synedra ulna	4				4.3		5			34.5	18.4		4	1					1					
Cladophora glomerata																			15%					
Stigeoclonium tenue	30%				P					P	P		30%	5%										

TABLE 42.4 (cont.)

RIVER TAME	DATE 26.7.1977												DATE 22.8.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Diatoma vulgare			F	F	F		1	NA	F	F	F		NA	NA	F	F	F			NA	F	F	F	
Gomphonema parvulum	3	3																						
Nitzschia palea	2	1																						
Rhoicosphenia curvata							1																	
Synedra ulna	5	4					3												1					
Cladophora glomerata							10%												5%					
Stigeoclonium tenue	5%	5%																						

TABLE 42.4 (cont.)

RIVER TAME	DATE 20.9.1977												DATE 17.10.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Diatoma vulgare			F	F	F		1	NA						1	F	F	F			NA	F			
Gomphonema parvulum	2	2											2	1								0	·2	
Melosira varians																						·2	0	
Navicula sp.																						·1	·1	
Nitzschia palea	3	3											2						1					
Rhoicosphenia curvata							1							1								·1	0	
Synedra ulna	2	2					2						1	1										
Chaetocium sp.									32	·1	18.1													
Cladophora glomerata		5%					40%							5%					40%					
Scenedesmus quadricauda	1												1											
Stigeoclonium tenue	30%	5%											30%									P	P	

TABLE A2.4 (cont.)

RIVER TAME	DATE 15.11.1977												DATE 13.12.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Gomphonema parvulum	NA	NA	F	F	F		NA	NA	1·8	O	O		NA	NA	F	F	F		NA	NA				
Melosira varians									·2	O	O													
Characium sp.									·2	O	O													
Stigeoclonium tenue									P	P	P													
Vorticella sp.									P	P	P										P	P	P	

TABLE A2.5

RIVER MEASE	DATE (2.5.1977) 30.5.1977						DATE 27.6.1977						DATE 26.7.1977						DATE 22.8.1977					
STATION	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cocconeis pediculus		NA	F	F	F		NA	NA	L	L	L		2	NA	–	–	–		2	NA	–	–	–	
placentula													3						2					
Gomphonema olivaceum													1						1					
Melosira varians																			1					
Navicula spp.	2																							
Nitzschia acicularis													2						1					
palea													3						1					
Rhoicosphenia curvata													5						1					
Cladophora glomerata	50%												40%						30%					
Enteromorpha intestinalis	25%												30%						20%					
Palmelloid green																			P					

TABLE A2.5 (cont.)

RIVER MEASE	DATE 20.9.1977						DATE 17.10.1977						DATE 15.11.1977						DATE 13.12.1977					
STATION	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis		U	F	F	F			1											NA	NA	F	F	F	
Bacillaria paradoxa									0	0	·1			2										
Cocconeis amphisbaena													1											
Cocconeis pediculus	2						2						2											
placentula	2						2		0	·1	·1													
Diatoma vulgare	1								0	0	·1													
Fragilaria capucina	1												1											
Frustulia rhomboides							1																	
Gomphonema olivaceum	2																							
parvulum																								
Gyrosigma attenuatum							1							2										
Melosira varians	1						2		0	0	·4		2	1										
Navicula spp.	2						4		·2	·1	·2		2	1										
Nitzschia acicularis	1																							
linearis									0	0	·1			2										
palea	2						1						1											
sigmoidea								1					1	2										
Rhoicosphenia curvata	4						4						3											
Surirella ovata	1																							
Synedra ulna	5						2		·1	0	·3													
Oscillatoria limosa							1																	
Cladophora glomerata	35%						50%						30%											
Closterium sp.	2						1						1	1										
Enteromorpha intestinalis	10%						10%																	

TABLE 42.6

RIVER DERWENT	DATE 1.6.1977 (6.5.1977)												DATE 29.6.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Caloneis amphisbaena		2	F	F			NP	U	F	F	F				F	F			NP		L			
Cymatopleura solea	1												1							1				
Cymbella prostrata	2												3							3				
Diatoma vulgare	3				2.6								2				.1			2		.1	0	
Fragilaria capucina	2				.3								1							1				
Gomphonema angustatum																	1.3							
olivaceum	2				3.6								2							2				
parvulum																	3.6					0	3.4	
Melosira varians	3				.7								3							4				
Navicula spp.	2	1			2.1								2	1			1.8			2				
Nitzschia acicularis		4											3	5						3				
linearis													1											
palea	3				5.8								3	3						3				
sigmoidea													1											
sublinearis		1																						
Rhoicosphenia curvata													3				1.1			2		0	.2	
Synedra ulna	4				17.4								2				.1			2		0	.1	
Lyngbya sp.														3										
Cladophora glomerata	40%												50%							5%				
Ulothrix zonata	2				P																			
Palmelloid green																	P						P	

TABLE A2.6 (cont.)

RIVER DERWENT	DATE 28.7.1977												DATE 26.8.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cocconeis placentula			F	F	F		NP	U	3.9	2.6	9.4		NA	NA	F	F	F		NP	NA	47	19.9	L	
Cymbella prostrata	1																							
Melosira varians	4	1																						
Navicula spp.	2																							
Nitzschia acicularis	1	2																						
palea	2	2																						
sigmoidea	1																							
Rhoicosphenia curvata	3	1							.8	.6	2.6											.2		
Synedra ulna	1	1																						
Cladophora glomerata	50%																							
Closterium sp.	1																							
Scenedesmus quadricauda	1																							
Palmelloid green									P	P	P										P	P		

TABLE 42.6 (cont.)

RIVER DERWENT	DATE	23.9.1977												DATE	21.10.1977											
STATION	1						2							1						2						
	R	P	S	S	S	M	R	P	S	S	S	M		R	P	S	S	S	M	R	P	S	S	S	M	
Achnanthes sp.	1		F				NP		E	E						F	F			NP	NA					
Amphora ovalis																						•1	0	0		
Caloneis amphisbaena		2		0	•1										3											
Cocconeis placentula				3·1	2·7			2			3·0			1				1·3				4·8	1·8	0		
Cymatopleura solea		1												1	1											
Cymbella prostrata	1													1												
ventricosa				•2	•1			1						1												
Fragilaria capucina	2													2												
Gomphonema olivaceum														1												
parvulum				6·6	2·3									1				•3				0	•3	0		
Gyrosigma attenuatum		1																								
Melosira varians	4			•7	1·4			3						4				•2				0	•4	1·2		
Navicula spp.	2	4		2·1	1·1									3	4			•2				•1	•1	0		
Nitzschia acicularis		4													2							0	•2	0		
linearis		2												2	2											
palea	2	4												1	2							0	0	•2		
sigma		1																								
sigmoidea	1	2		0	•1									2	2											
tryblionella															2											
Rhoicosphenia curvata	3			7·4	2·4			2						2								3·4	1·0	0		
Synedra ulna	3	1												2								0	0	•3		
Chamaesiphon sp.				•1	•5									1												
Oscillatoria sp.		1												1	1											
Characium sp.																						•1	0	0		
Cladophora glomerata	50%							5%						35%												
Pediastrum boryanum														1												
Palmelloid green				P	P						P							P				P	P	—	
Rhodochorton violaceum														1												

TABLE 42.6 (cont.)

RIVER DERWENT	DATE 18·11·1977												DATE 16·12·1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Vorticella sp.	NA	NA	I	I	I		NP	NA	I	I	I		NA	NA	F	F	L		NP	NA	P	P	P	

TABLE 42.7

RIVER TEAN	DATE 16.3.1977 (First Visit)												DATE 13.4.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.		U						U					2							U				
Cocconeis placentula	1																							
Cymbella prostrata															·1	·1	·1				·1	·2	·1	
Gomphonema olivaceum													2		4·2	12·2	3·1				·1	·4	·8	
parvulum													2		·8	1·3	·6				·3	2·6	1·4	
Melosira varians													2											
Meridion circulare													2		5·6	19·1	4·3		1		·3	·2	·2	
Navicula spp.	3												4		20·8	11·1	9·6		2		·2	4·3	1·0	
Nitzschia palea													4		38·0	26·3	40·0		3		·6	20·0	28·4	
Rhoicospheria curvata															2·3	·8	·6		2		·9	1·3	·7	
Synedra ulna	1												3	2	4·7	5·2	4·1		1		·2	2·6	·6	
Cladophora glomerata	5%						5%						5%						10%					
Rhodochorton violaceum	2												1						3					

TABLE 42 7 (cont.)

RIVER TEAN	DATE 11.5.1977												DATE 9.6.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.															·1	·2	·1				F	F	F	
Diatoma vulgare	2												1						1					
Caloneis amphisbaena														2										
Cocconeis placentula															·3	·7	·5							
Gomphonema olivaceum	1		3·3	2·7	·8		2		·1	·2	·3													
parvulum									11·5	6·3	15·1								2					
Meridion circulare	1																							
Navicula spp.	1			·2	·3		4		·5	8·4	1·6		1	2					2					
Nitzschia linearis		1																						
palea							3																	
Rhoicosphenia curvata															·3	·4	·2							
Synedra ulna	1		·2	·4	·3		1		·1	·3	·2								1					
Cladophora glomerata	5%						40%	40%					5%	5%					70%	70%				
Rhodochorton violaceum	1												2						3					

TABLE 42 7 (cont.)

RIVER TEAN	DATE 6.7.1977												DATE 3.8.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.	2		17.4	24.5	21.3				L	F	F				U	U	U				F	F	F	
Caloneis amphisbaena		1												1										
Cocconeis placentula	1		2.4	.4	.2																			
Cymatopleura solea		1																		1				
Cymbella prostrata	1		.2	.2	0																			
Diatoma vulgare	2																							
Gomphonema olivaceum	1		2.6	2.2	5.3																			
parvulum	1		.2	.3	.6																			
Gyrosigma attenuatum		1																						
Melosira varians	2	2											1											
Navicula hungarica		3																						
spp.	2	2	.1	.1	.2																			
Nitzschia acicularis		1																						
linearis		4											1	1										
palea			.7	.2	.2																			
sigmoidea		1																						
Rhoicosphenia curvata	1		.1	.4	.6																			
Lyngbya sp.	1																							
Cladophora glomerata							50%	60%											40%	60%				
Closterium sp.																				2				
Palmelloid green			P	P	P														P					
Rhodochorton violaceum	2						4						1						1					

TABLE 42.7 (cont.)

RIVER TEAN	DATE 1·9·1977												DATE 29·9·1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			·2	0	0				F	F	F				·8	1·1	·8				F	F	F	
Caloneis amphisbaena														1										
Cocconeis placentula	1			5·3	3·1	2·6							1		5·2	8·4	9·2							
Cymatopleura solea		1																						
Gomphonema parvulum															0	·4	·1							
Gyrosigma attenuatum																				1				
Melosira varians	1																							
Navicula spp.	1	1		·1	0	·1							1	1										
Nitzschia palea		1																						
sigmoidea		1												2										
Rhoicosphenia curvata	1			·9	0	0							1		·2	·7	1·3							
Synedra ulna	1	2																						
Oscillatoria sp.		1																						
Cladophora glomerata							40%	40%											40%	30%				
Closterium sp.																				1				
Rhodochorton violaceum	1						2						1											

TABLE A2.7 (cont.)

RIVER TEAN	DATE 25·10·1977												DATE 22·11·1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cocconeis placentula	1		·8	·7	·6				F	F					U	U					F	F	F	
Cymatopleura elliptica			·1	0	0																			
Gomphonema parvulum											·9													
Gyrosigma attenuatum	1																							
Melosira varians			0	·2	1·1																			
Navicula spp.	2		·2	0	·2		1						2	1			·1							
Nitzschia linearis			·1	·1	1·4									1										
palea			0	0	·2						·2													
sigmoidea		1	0	0	·2																			
sublinearis			0	0	·3																			
Rhoicosphenia curvata	1		·3	0	0								2											
Cladophora glomerata							20%	20%											5%					
Rhodochorton violaceum	3												2						2					

TABLE A2.8

R.CHURNET 17·3·1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes spp.	2										1	1		1
Amphora ovalis					1									
Cocconeis spp.	1										1			
Cymbella spp.					1									2
Diatoma hiemale	1													
vulgare					2						1			1
Fragilaria capucina												1		1
Gomphonema parvulum					1			1			1			
Melosira italica					2						1			1
varians					1						1			1
Meridion circulare	1	1	1		2					1	1	2	1	1
Navicula spp.	5	2	1		1		1	1	3	4	2	2	2	2
Nitzschia acicularis											1	1		
dissipata	1		1		1									
palea								1						
Pinnularia sp.					1									
Surirella ovata	1		1		1					1	1	1		
Synedra ulna					1		1	1		1	2	1	1	2
Tabellaria flocculosa	2													
T. flocculosa v. asterionelloides					1									
Oscillatoria agardhii			1		1									
limosa			4											
Chlorococcum sp.												2		
Drapanaldia plumosa					3									
Ulothrix zonata			2		1									
Vaucheria sp.					2									2
Batrachospermum moniliferum	2													
Lemanea fluviatilis	2		3											
Rhodochorton violaceum														1
Sewage Fungus							5	5	3		3		1	
Indeterminate ①		5												

TABLE A2.8 (cont.)

R.CHURNET 14·4·1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes spp.	1		2				1							
Cymbella spp.				4	3			1				2		1
Diatoma hiemale	1													
vulgare				4	5	4	3	2			2		2	2
Fragilaria capucina	1		1											
Gomphonema olivaceum	1													
Melosira italica				2	1	1								
varians							1				2			2
Meridion circulare	1	1	4			1	2	1		2	2			
Navicula spp.	5	1	2	1		1	2	2	4	5	4	5	5	4
Surirella ovata	1	1	3	3	2	2	2	3	2	2	1	2	1	2
Synedra ulna	1			1	3	2	2	4	2	2	3	2	2	2
Tabellaria flocculosa	1		2											
Oscillatoria limosa			1											
Cladophora glomerata														25%
Microspora amoena							2							
Stigeoclonium tenue									1	2				1
Ulothrix zonata				3	2	1	1							
Vaucheria sp.							2		2		2	2	3	2
Lemanea fluviatilis	2		3											
Sewage Fungus						3								
Indeterminate ①		5	1											

TABLE A2.8 (cont.)

R.CHURNET 12·5·1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Cymbella spp.				2	2	2	2	1	2			1		
Diatoma vulgare				4	5	4	2	2	3	1	1	1	2	2
Fragilaria capucina				1					2					
Melosira italica				2	2									
varians										1	1		1	1
Meridion circulare	2		2	1					1					
Navicula spp.	3		2	1	1		3	3	3	2	2	5	2	2
Surirella ovata			2	2			2	1	2		1	1		
Synedra ulna	1		2	1	1		3	3	4	3	5	1	2	2
Phormidium inundatum			2			4								
Cladophora glomerata										5%		5%	30%	30%
Draparnaldia plumosa					3									
Microspora amoena							3							
Stigeoclonium tenue								3						
Ulothrix zonata			1	2	1	3	2	1	1			1		
Vaucheria sp.									2	2	2			
Batrachospermum moniliferum	2													
Lemanea fluviatilis	2		3											
Indeterminate ①		4												

TABLE A2.8 (cont.)

R.CHURNET 10.6.1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes spp.	1				1									
Cymbella spp.			2	1	3	1	1					1	1	1
Diatoma vulgare				2	4	2	2	2	1	1	2	2	2	3
Fragilaria capucina				1	1				1		1	1		
Gomphonema olivaceum	1	1					1		1	1	1	1		1
Melosira italica				1	1	1								
varians								1	2	2	2	2	3	3
Meridion circulare	1													
Navicula spp.	3	2	3	1	1		1	1	1	1	2	2	3	2
Nitzschia linearis									1	1		1		
palea	1		1	1	3	2	2	1	1		1	1	1	1
sigmoidea												1		
Synedra ulna	3	1	2	1	1	1	3	1	1	1	2	1	1	1
Tabellaria flocculosa	1													
Oscillatoria spp.		1					1	2		1			1	
Cladophora glomerata						10%		10%	15%	10%	10%	5%	15%	15%
Closterium sp.			1	1										
Microspora amoena							4	1		1				
Staurastrum sp.				1	1									
Stigeoclonium tenue													1	
Ulothrix zonata			1	1	1			1		1				
Vaucheria sp.									2		2			
Lemanea fluviatilis	2		3											
Rhodochorton violaceum							3			3				
Sewage Fungus						5								
Indeterminate ①		2												

TABLE A2.8 (cont.)

R.CHURNET 7.7.1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes spp.	2		1									1		
Amphora ovalis			1	1									1	1
Cocconeis spp.												1	1	1
Cymatopleura solea										1				1
Cymbella spp.	1		3	2		1			1			1		
Diatoma vulgare				2	1	1					1	1	2	1
Fragilaria capucina				2	1	1								1
Gomphonema olivaceum	2	1	1				1		1					
parvulum							1	1	1	1				
Melosira italica				2	1									
varians				1					1		1	1	3	4
Meridion circulare	2													
Navicula spp.	3	1	4	1	1	1	1						1	1
Nitzschia acicularis				4	1				2	1	1	1	1	2
linearis											1	1	1	2
palea	1		1	2	1	2	2		2	1	1	1		2
sigmoidea											1	1	1	1
Rhoicosphenia curvata	1												1	4
Surirella ovata	1	1	1				1		2					
Synedra ulna	2	1	1	1		1	1				1			
Tabellaria flocculosa	1													
Oscillatoria sp.		1				1	2			1				
Cladophora glomerata								50%	10%	10%	5%	5%	5%	5%
Closterium sp.			1	1	1									
Cosmarium sp.				1										
Microspora amoena							4	1	1	1				
Scenedesmus quadricauda											1			
Staurastrum sp.				1										
Ulothrix zonata	1			1									1	
Vaucheria sp.									1					
Lemanea fluviatilis	2		3											
Rhodochorton violaceum										2	2	1		
Sewage Fungus						5								
Indeterminate ①		2												

TABLE A2.8 (cont.)

R.CHURNET 4.8.1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes spp.	3								1		1	1		
Cocconeis spp.									1	1	1		1	1
Cymatopleura solea													1	1
Cymbella spp.	1	1	2	1	1	1			1	1	2	1	1	1
Diatoma vulgare				2	1				1	1				1
Fragilaria capucina				2							1			1
Gomphonema olivaceum										2	1		1	1
parvulum	1								1	2	1			1
Melosira italica					1	1								
varians			1	2	1			1	3	4	2	3	3	3
Meridion circulare	1													
Navicula spp.	2	3	3	1	1	1	1		1	1	1	2	1	1
Nitzschia acicularis			2						3	1	1	2	2	2
linearis		1	2	1		1			1	1	1	1	1	1
palea		2	2	1	1		1		1	1	1	2	2	1
sigmoidea										1	2		2	2
Rhoicosphenia curvata	1												1	1
Surirella ovata										1	1		1	1
Synedra ulna	2	1	2	1	1	1		1	3	4	2	1	1	1
Lyngbya sp.						2								
Oscillatoria sp.		1								2				
Chlorococcum sp.											2			
Cladophora glomerata					5%		30%	20%	20%	40%	10%	15%	10%	10%
Closterium sp.	1	1	2	1	1									
Cosmarium sp.		1	1	1										
Microspora amoena	2						4	1						
Scenedesmus quadricauda										1				
Vaucheria sp.							2		1		2	1	1	1
Lemanea fluviatilis	2		2											
Rhodochorton violaceum										2		1	1	1
Sewage Fungus						4								
Indeterminate ①		1												

TABLE A2 8 (cont)

R.CHURNET 2.9.1977	T	!	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes sp.	2		2								1			
Amphora ovalis												1		
Asterionella formosa				3	2	2								
Cocconeis spp.											1	1	1	2
Cymatopleura solea												1	1	1
Cymbella spp.		1		1	1			1	1	1			1	1
Diatoma vulgare				2		1			1				1	1
Fragilaria capucina				2	1							1	1	1
crotonensis				1										
Frustulia rhomboides											1	1		
Gomphonema constrictum				1	1									
olivaceum									1	2	1			2
parvulum							1	1		1	1			
Melosira italica				1	2	2	1	1						
varians		1	2	3	2		1	1	4	5	1	3	2	2
Navicula spp.	2	2	2	2	1	1		1	1	1	2	2	1	1
Nitzschia acicularis		1	1	1	1				1	1	1			1
linearis		3	2							1	1	1		
palea		1	1	1			1	2	1	1	1	1	1	1
sigmoidea									1	1			1	
sublinearis										1		1		
Pinnularia sp.				1										
Rhoicosphenia curvata	2												1	2
Surirella ovata		1	1						1	1	1		1	
Synedra acus											1			
ulna	1	2	2	1	2		2	1	2	1	1			1
Lyngbya sp.		3												
Oscillatoria sp.					1					1			1	
Ankistrodesmus sp.				1										
Cladophora glomerata					10%		20%	25%	20%					
Closterium sp.	1	1	1	1	3	3								
Microspora amoena							2							
Scenedesmus quadricauda				1	1					1	1			
Sporotetras sp.							2							1
Staurastrum sp.		1	1	1		1								
Ulothrix zonata	1		1			1			1	1				
Vaucheria sp.											2		2	2
Rhodochorton violaceum										3	1	1	1	1

TABLE A2.8 (cont.)

R.CHURNET 30.9.1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes spp.	1	1		1			1		1	1	1		1	
Cocconeis spp.										1			2	2
Cyclotella meneghiniana							1	3	2	1	1			
Cymbella spp.			1		1				1	1	1		1	1
Diatoma vulgare				1	1	1	1			2			1	2
Fragilaria capucina										1			1	
crotonensis				1	1									
Gomphonema parvulum							1	3	2	2	1			1
Melosira italica				2	1	1	1							
varians		1	3	2		1			3	3	3	2	2	3
Navicula spp.	1	1	2	2	1	1	1	2	1	2		1	1	1
Nitzschia acicularis				1	1			2	1	1		1		1
linearis							1		1	1	1	2	1	
palea			2		2	1	1	3	1	2		1	1	
sigmoidea										1	1	2	1	1
sublinearis										1	1			1
Pinnularia sp.				1			1	1						
Rhoicosphenia curvata												1	1	1
Synedra ulna			1				1	1	1	1	1		1	
Tabellaria flocculosa				3	2	2								
Chamaesiphon sp.										1	1			
Oscillatoria agardhii			1											
limosa		1												
tenuis						2	2	1		1	1			
Chlorococcum sp.										2	1			
Cladophora glomerata					10%		10%	15%	25%				10%	10%
Closterium sp.				1		1								
Microspora amoena							2			1	2		1	
Oedogonium sp.				1										
Pediastrum duplex											1			
tetras										1				
Scenedesmus accuminatum										1				
quadricauda						1	1		1	1	1			1
Staurastrum anatinum					1									
Ulothrix zonata				1										
Vaucheria sp.										1	2		2	2
Rhodochorton violaceum									3	4	3	1	1	1
Sewage Fungus								5						

TABLE 42.8 (cont.)

R.CHURNET 26.10.1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes spp.									1	1		1		
Amphora ovalis										1	1	1		
Cocconeis spp.									1	1	1			1
Cyclotella meneghiniana							2			1				
Cymatopleura elliptica													1	
solea												1		
Cymbella lanceolata														1
spp.			1	2	2					1		1	1	1
Diatoma vulgare				2	2	1	1			2	1		2	3
Fragilaria capucina				1	1								1	
crotonensis				1	1									
Frustulia rhomboides											1	1		
Gomphonema constrictum					2									
oliviaceum			1										1	1
parvulum					1			2	1	1	1			
Melosira italica					2	1	1	1						
varians			1	3			1	1	3	3	3	3	3	3
Navicula spp.	1	2	3	2	2	1	1	2	2	2	2	2	2	1
Nitzschia acicularis									1	1	1		1	
linearis				2	2	1		1	1		1	2		1
palea		1	1	3	3	1	1	2	2	2	2	2	2	1
sigmoidea									1	1	1			
sublinearis				1	2	1					2	1		1
Pinnularia sp.					1	1								
Rhoicosphenia curvata	1										1	1	2	3
Surirella ovata		1	1											
Synedra acus										1	1	1		
ulna	1		1	1	2		3	2	2	1	2	2	2	2
T. flocculosa v. asterionelloides				3	3	2	1							
Merismopedia glauca									1					
Oscillatoria limosa		1	2											
tenuis						1								
Phormidium inundatum		2												
Chlorococcum sp.										1	1			
Cladophora glomerata					10%		30%		30%	30%	15%	10%	15%	15%
Closterium sp.				1	2	1								
Cosmarium sp.					1									
Microspora amoena							2			1			1	
Mougeotia sp.		1												
Pediastrum duplex					1									
Scenedesmus quadricauda									1	1	1			
Spirogyra sp.							2							
Stigeoclonium tenue									2					
Ulothrix zonata		1		1										
Vaucheria sp.							1							2
Rhodochorton violaceum				3	3				3	4	3	2	2	2
Sewage Fungus						5		4						

TABLE A2.8 (cont)

R.CHURNET 23.11.1977	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes spp.	1						1					1		
Cocconeis spp.														1
Cymbella spp.				1	1									1
Diatoma vulgare				1										1
Gomphonema constrictum				1	1	1								
parvulum							1							
Melosira italica					1									
varians				1	1		1		1	1	2	2		2
Navicula spp.				2	1	1	1		2	1	1	1		2
Nitzschia communis				1										
linearis					1							1		1
palea				1	1		1					1		1
sigmoidea														1
sublinearis						1								
Rhoicosphenia curvata														1
Synedra acus										1		1		
ulna					1		1							
T. flocculosa v. asterionelloides				1										
Oscillatoria agardhii									2					
limosa				1										
tenuis											1			
Cladophora glomerata					5%		5%	10%	10%			5%		15%
Drapamaldia plumosa				1										
Ulothrix zonata				1		1								
Vaucheria sp.					1				2			2		
Rhodochorton violaceum				2	2				2	3	1	1		2
Sewage Fungus						2		3						

TABLE A2.8 (cont.)

R.CHURNET 21.2.1978	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes affinis							2							
lanceolata	2		2		2		2		2					
Cocconeis pediculus							1		1				1	1
placentula													1	1
Cyclotella kuetzingiana	1				1		2							
Cymbella cuspidata					1									
prostrata					3									
ventricosa	1		1		3									1
Diatoma hiemale	1													
vulgare					1	1	1	1						
Eunotia sp.	1													
Gomphonema olivaceum			1		1									
parvulum					1		2		1					
Melosira italica					1									
varians							2			1	1		1	2
Meridion circulare	1													
Navicula cryptocephala					1		1							
gastrum									2				2	2
placentula	3		1	1	1	1	1	2	2	1	1	2	2	2
viridula	5	1	1	3	2	2	3	2	2	1	1	3	3	3
Nitzschia amphibia					1									
dissipata	3				2				1					1
linearis													1	
palea									1					
Rhoicosphenia curvata	1				1				1				1	2
Surirella ovata	2		1		1		1							
Synedra acus								1			1	1	1	1
ulna					1		1						1	
Tabellaria flocculosa	1				1									
Oscillatoria agardhii				2		2	2							
limosa	1													
Cladophora glomerata														5%
Microspora amoena							2							
Ulothrix zonata					2									
Lemanea fluviatilis	2		2		2									
Rhodochorton violaceum	1		1	3		2	3					2	1	3
Sewage Fungus						1								
Indeterminate ①		1												

TABLE A2.8 (cont.)

R.CHURNET 21.3.1978	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes lanceolata	2		1	1	1		NA		NA	NA	NA	NA	NA	NA
Cyclotella kuetzingiana								1						
Cymbella ventricosa	2		2	3	3	3		2						
Diatoma hiemale	1													
vulgare				1	2	1								
Eunotia sp.			1											
Gomphonema constrictum					1									
olivaceum			1											
parvulum			2		2	2		3						
Hantzschia amphioxys			1											
Melosira varians			1		2	1								
Meridion circulare	2	1	2	1										
Navicula cryptocephala								1						
gastrum								1						
hungarica								1						
minima	1													
placentula	2		2	2	2	2								
viridula	5	1	2	3	3	3		3						
Nitzschia amphibia								1						
dissipata	1		2	2	2	1								
linearis			1											
Pinnularia mesolepta	1													
Pinnularia sp.			1		1									
Rhoicosphenia curvata	2													
Surirella ovata	2		3	1	1	1		1						
Synedra ulna			1		1	1								
Tabellaria flocculosa	1													
Lyngbya aeruginea-caerulea			1											
Oscillatoria agardhii				1										
Ulothrix zonata			1	2	3									
Lemanea fluviatilis	2		3											
Sewage Fungus								3						
Indeterminate (1)		3	2											

TABLE A2.8 (cont.)

R.CHURNET 18.4.1978	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes affinis									1				L	1
lanceolata	2	2	2			1	1		2					
Asterionella formosa				2	1									
Cocconeis pediculus												1	1	1
Cyclotella kuetzingiana		2	2	3			3		2					
meneghiniana											1	1	1	1
Cymatopleura elliptica												1		
Cymbella prostrata														1
ventricosa	1	2	2	3	3	4	2	2	1			1		
Diatoma hiemale	1													
vulgare				3	2	1	2	2	1				1	
Eunotia sp.		1												
Fragilaria capucina		1												
Frustulia rhomboides												1		
Gomphonema acuminatum												1		
olivaceum				1										
parvulum	1		1	1	1		1	2	3					
Hantzschia amphioxys		1												
Melosira italica				3	2	2	1	1	1	1	1	1	1	1
varians										1	1	1		
Meridion circulare	1	1	3		1		1		1	1	1	1	1	1
Navicula cryptocephala								1						
gastrum							2				1			
placentula	2	2									2			
viridula	5	3	3	2	3	3	2	3	2	3	3	3	3	3
Nitzschia acicularis								1						
amphibia							1							
dissipata	1		1	1										
linearis			1								1	1	1	1
palea					1	1	1	1	2	2				
Rhoicosphenia curvata												1	1	1
Surirella ovata	1	3	3	1	2	2	2	2	2	3	3	3	3	3
Synedra acus							2	2	1	1			1	1
ulna	1				1	1	3	3	2	2	2	1		
Tabellaria flocculosa	1			1										
T. flocculosa v. asterionelloides				3	2	1	1							
Lyngbya sp.				1										
Oscillatoria agardhii		2	1			1								
Oscillatoria sp.	1								2	2		2	2	
Phormidium inundatum						2								
Cladophora glomerata								5%				5%		25%
Microspora amoena							4	2			1			
Stigeoclonium tenue									3	1	1		2	2
Ulothrix zonata			2	2		2								
Vaucheria sp.				2			4		2	2	2	2	3	3
Batrachospermum moniliferum					1									
Lemanea fluviatilis			4											
Rhodocherton violaceum					3									1
Sewage Fungus						2		5						
Indeterminate (1)		4												

TABLE A2.8 (cont)

R.CHURNET 17.5.1978	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Achnanthes lanceolata	4	2	1	1	1	1	1		1	1	1	1	1	2
Asterionella formosa				2	2	1								
Cyclotella comta									1					
kentzingiana				2	2	1	1				1			
meneghiniana						1	1	1	1					1
Cymbella prostrata				2	2	1								1
ventricosa	2	2	2	4	4	3			1	1	1			2
Cymatopleura elliptica												1		
Solea											1			
Diatoma elongatum									1					
hiemale	1													
vulgare				4	3	2	1				1			
Fragilaria capucina		1		2	3	2								
crotonensis				1										
vaucheriae									1					
Frustulia rhomboides												1		
Gomphonema constrictum					1									
olivaceum		1						1	1			1		1
parvulum				1	1		2	2	3	2	1		1	1
Gyrosigma attenuatum													1	
Melosira italica				2	2	2			1					
varians		2					1	1	1	1	1	1	1	1
Meridion circulare	2	1							1	1	1	1		
Navicula cryptocephala					2				1			1		
gastrum						1	1	1			1	1		
hungarica								1						
pelliculosa									3					
placentula	3	2	2		1	1			2			1		1
viridula	5	3	2	2	2	4	1	2	2	2	1	2	1	2
Nitzschia acicularis								2						
dissipata					2	2			1					1
hybrida														1
linearis									1	1	2	2	1	1
palea						2	2	2	2					
sigmoidea													1	
tryblionella														1
Pinnularia mesolepta	1													
viridis					1							1		
Rhoicosphenia curvata	1								1					
Surirella ovata	1	5	1	2	2	2	1	2	3	3	3	3	2	3
Synedra acus									2	1				
ulna	1	2		2	1	2	4	5	2	2	2	2	2	3
Tabellaria flocculosa	1													
T. flocculosa v. asterionelloides				2	2	1	1	1	1					
Oscillatoria limosa							2							
tenuis		2	2											
Phormidium inundatum		2												
sp.						2								
continued overleaf														

TABLE A2.8 (cont.)

R.CHURNET 17.5.1978 (continued)	T	1	2	3	4	5	6	7	8	9	10	11	12	13
Cladophera glomerata						5%	10%	5%	5%				25%	40%
Closterium sp.				1	1	1								
Microspora amoena							5	2						
Scenedesmus quadricauda									1				1	
Spirogyra sp.							3	1						
Staurastrum sp.				2	1	1								
Stigeoclonium tenue									2	3	2			
Ulothrix zonata		1	2	4	2						3			
Vaucheria sp.								1	2	3	2	2	3	2
Batrachospermum moniliferum					1									
Lemanea fluviatilis			4						2					
Rhodochorton violaceum							3	1	1				1	1
Sewage Fungus								5						

TABLE A2 8 (cont.)

RIVER CHURNET	DATE 14.4.1977 (17.3.1977)												DATE 12.5.1977											
STATION	6						10						6						10					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			·2	·1	·4				5·8	3·7	U				U	U	U							
Cymbella sp.			·4	·6	·8																·4	·3	·2	
Diatoma vulgare			2·2	·8	·6																·4	·5	·2	
Gomphonema olivaceum			4·5	3·1	·7				3·8	O											24·3	16·7	3·2	
Melosira italica			2·6	5·3	·9																			
Meridion circulare			·2	·1	·1																			
Navicula spp.			3·2	2·1	1·4																6·4	7·6	1·4	
Nitzschia palea									10·6	3·9											3·5	4·1	·6	
Synedra ulna			1·2	1·0	·8				O	·3											O	·8	O	

TABLE 42 8 (cont.)

RIVER CHURNET	DATE 10·6·1977												DATE 7·7·1977											
STATION	6						10						6						10					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			0	0	·3				1·6	1·9	1·4				U	U	U							
Cymbella sp.			0	0	·4				·3	·5	·3													
Diatoma vulgare									·4	·2	·2													
Gomphonema parvulum			·6	·3	·3				0	·4	·2													
Melosira varians									0	·5	·2													
Navicula spp.									2·1	1·1	1·7													
Nitzschia palea									·7	·3	2·8													
sublinearis									0	·1	·2													
Rhicosphenia curvata									·4	0	0													
Synedra ulna			·2	·1	·4				·5	·4	·7										·1	0	·2	
Palmelloid green																					P	P	P	

TABLE A2 8 (cont.)

RIVER CHURNET	DATE 4·8·1977												DATE 2·9·1977											
STATION	6						10						6						10					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			U	U	U				2·3	3·1	2·9				U	U	U							
Cocconeis placentula									2·1	2·3	3·4													
Fragilaria capucina									·1	0	0													
Gomphonema olivaceum																					·1	0	0	
Melosira varians									·9	·4	·1										2·3	·5	·6	
Navicula spp.									·4	1·3	·6										0	0	·1	
Nitzschia linearis									0	0	·2										·1	·1	·2	
palea									·8	·2	·1													
sigma									0	·1	0										·1	0	0	
sigmoidea									·1	·2	·1													
sublinearis									·2	·1	0													
Syncdra ulna																					·8	·1	0	

TABLE 42.8 (cont.)

RIVER CHURNET	DATE 30.9.1977												DATE 26.10.1977											
STATION	6						10						6						10					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.			U	U	U				O	·3	·8				U	U	U				·4	·2	·9	
Amphora ovalis									·1	·1	O										·1	·1	·1	
Cocconeis placentula																					·6	·2	1·3	
Cymbella sp.									·1	O	O													
Gomphonema parvulum																					·7	·1	·2	
Melosira varians									·4	·5	1·4										1·4	·8	·6	
Navicula spp.									·6	·3	·2										·1	O	·1	
Nitzschia acicularis																					·1	O	O	
linearis									1·2	·8	·3										·8	·9	·8	
palea																					·3	·1	·2	
sigmoidea									·1												·1	O	·1	
Synedra ulna																					·1	O	·2	

TABLE 428 (cont.)

RIVER CHURNET	DATE 23.11.1977												DATE											
STATION	6						10																	
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Melosira varians			U	U	•3				U	U	U													
Nitzschia linearis					•1																			

TABLE A2.9

RIVER SEVERN	DATE		18.5.1977				(20.4.1977)						DATE		15.6.1977									
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cymbella ventricosa	NA	NA	1·4	2·1	·8		NP	NA	·4	1·4	·5		NA	NA					NP	NA				
Diatoma vulgare									0	·3	·4													
Gomphonema olivaceum			2·3	·7	·5				1·8	6·4	0													
Gyrosigma attenuatum			·1	0	·2																			
Melosira varians			·3	·4	·4				0	1·7	·7										·2	·5	·4	
Navicula spp.			6·2	1·4	17·3				19·5	4·8	1·9				1·9	3·3	2·1				·3	·1	·3	
Nitzschia acicularis															·5	·2	·2				·7	·6	·4	
palea			8·3	·9	4·6				7·3	8·8	2·4				·1	·3	·4				3·6	2·8	4·3	
sigmoidea			·1	0	·1				·1	0	0													
Rhoicosphenia curvata			1·2	·7	·3				·8	·4	·5													
Synedra ulna			1·9	·9	2·2				8·2	4·7	1·3										·5	·7	·4	
Palmelloid green															P	P	P				P	P	P	

TABLE 42.9 (cont.)

RIVER SEVERN	DATE	13.7.1977												DATE	10.8.1977											
STATION	1						2							1						2						
	R	P	S	S	S	M	R	P	S	S	S	M		R	P	S	S	S	M	R	P	S	S	S	M	
Achnanthes sp.		NA	E				NP	NA	F	2.7	2.1				NA					NP	NA					
Amphora ovalis				0	.1									1												
Cocconeis placentula	3			4.8	.3					3.3	5.2			4		.9	.2	.4				3.3	12.7	1.3		
Cyclotella meneghiniana														2												
Cymatopleura solea														1												
Cymbella ventricosa										1.8	0															
Diatoma vulgare	2																									
Gomphonema parvulum				2.3	0					1.9	1.2															
Gyrosigma attenuatum	1																									
Melosira varians	1									.4	0											.2	0	.4		
Navicula spp.	1			0	.9					3.7	1.1			2								.1	0	2.7		
Nitzschia palea	2			0	1.2					3.0	0			1												
Rhoicosphenia curvata	3			.7	0									1								0	.1	0		
Cladophora glomerata	30%													30%												
Scenedesmus quadricauda																						.1	.1	.2		
Filloid green				P	P					P	P					P	P	P				P	P	P		

TABLE A2.9 (cont.)

RIVER SEVERN	DATE 8.9.1977												DATE 7.10.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis		NA	0	·1	0		NP	NA	·1	·3	0		NA	NA	·1	·2	·2		NP	NA				
Bacillaria paradoxa									·1	0	0													
Cocconeis placentula	4		14.7	9.4	5.3				3.1	0	1.0				·1	1.2	1.4							
Cyclotella meneghiniana			·5	1.3	·7																			
Cymbella lanceolata	1								·7	0	0													
ventricosa	1																							
Diatoma vulgare	1																							
Gyrosigma attenuatum	1		0	·1	·1				·2	0	0				·1	·1	·7				0	0	·1	
Melosira varians	3		2.3	8.9	2.8				·8	·6	·4				·4	·3	·4				2.1	2.6	4.6	
Navicula spp.	1		·4	4.7	6.1				5.2	0	4.8				·5	·7	1.1				0	2.7	1.3	
Nitzschia linearis																								
palea	2		·2	1.6	1.2				·1	0	·2				·3	·9	·4				·1	·2	·2	
sigmoidea															0	·1	·1				0	·1	0	
sublinearis															·1	·2	·1				0	·4	·1	
Rhoicosphenia curvata	2		·1	0	0										·1	0	0							
Synedra ulna									·2	·1	0				0	0	·1				·1	0	0	
Oscillatoria sp.																					P	P	–	
Cladophora glomerata	20%																							
Closterium sp.																					·1	·1	0	
Scenedesmus quadricauda			0	·1	·1																·1	0	·1	
Stigeoclonium sp.			P	P	P																			
Pediastrum boryanum			0	·1	0																			
Ulothrix zonata	2																							
Palmelloid green			P	P	P				P	P	P													

TABLE A2.9 (cont.)

RIVER SEVERN	DATE 7.11.1977												DATE 2.12.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis	NA	NA	U	U			NP	NA	U	•1	•1		NA	NA	U	U	U		NP	NA	U			
Gyrosigma attenuatum																						O	•1	
Melosira varians					•2					•4	O											•2	•6	
Navicula spp.					•1					•2	•1											•1	•1	
Nitzschia acicularis										O	•2												·	
linearis										•1														

TABLE A2.10

RIVER WYE	DATE 13.7.1977 (15.6.1977)												DATE 10.8.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.	NP	NA	L	L			NP	NA	.3	.4	0		NP	NA	L	U	U		NP	NA				
Cocconeis placentula					4.5				23.1	17.7	15.9										6.4	1.1	3.8	
Cymbella ventricosa									0	.2	.1													
Navicula spp.									.4	.3	1.8										4.1	.3	4.9	
Nitzschia palea									1.9	.6	.4													
Palmelloid green					P				P	P	P										P	P	P	

TABLE 42.10 (cont.)

RIVER WYE	DATE 8.9.1977												DATE 7.10.1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis	NP	NA	U	O	·1		NP	NA	1·2	1·6	1·9		NP	NA	U				NP	NA	U	O	·1	
Cocconeis placentula									·1	·1	·6					·1	O					·1	·1	
Diatoma vulgare																						O	·3	
Cymbella ventricosa									O	·1	O													
Fragilaria capucina				·1	O																	O	·1	
Melosira varians				·9	·2				4·6	·8	1·7					O	·3					O	1·9	
Nitzschia palea																						2·1	·4	
sublinearis																						O	·1	
Navicula spp.				1·5	O				·3	2·2	2·5					·3	·1					·6	2·2	
Rhoicosphenia curvata									O	·1	O											·1	·1	
Synedra ulna				·1	O																	O	·1	
Pediastrum boryanum				·1	O																			
Palmelloid green									P	P	P													

TABLE A2.10 (cont.)

RIVER WYE	DATE 7·11·1977												DATE 2·12·1977											
STATION	1						2						1						2					
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Gyrosigma attenuatum	NP	NA	U	U	U		NP	NA	U	U	U		NP	NA	U	U	U		NP	NA	U	O	·1	
Navicula spp.																						·1	·2	
Nitzschia palea																						O	·2	
linearis																						O	·2	

TABLE A2.11

RIVER NENE DATE 9.3.1977 (First Visit)

STATION	1						2						3											
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis	NA	1					U	U					U	U										
Cymatopleura elliptica		1																						
solea		1																						
Melosira varians		1																						
Navicula spp.		1																						
Nitzschia sigmoidea		1																						
sublinearis		1																						
Pinnularia viridis		1																						
Surirella elegans		1																						
Synedra ulna		1																						

TABLE A2.11 (cont.)

RIVER NENE — DATE 6.4.1977

STATION	1						2						3											
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Amphora ovalis	NA	1	U					1	U					1	E	E	E							
Caloneis amphisbaena								2																
Cocconeis placentula													2											
Cymatopleura solea		1						2																
Cymbella ventricosa				.2	.3			1		.1	.4													
Diatoma vulgare				.3	.4		1			.5	.3													
Fragilaria capucina				.2	0								1											
Gomphonema olivaceum				12.1	58.9					6.9	7.2		2											
Gyrosigma attenuatum								1						1										
Melosira varians		1		.4	.1			1		.6	.2		2											
Meridion circulare				.3	.4					.1	0		1											
Navicula hungarica v. capitata								2						3										
spp.				7.5	4.9		5	1		9.1	6.8		4	1										
Nitzschia acicularis								1						1										
palea								2					3	2										
sigma								1																
sigmoidea		3												1										
sublinearis				1.6	2.1					.1	0													
Rhoicosphenia curvata													2											
Surirella elegans		1																						
ovata													1											
Synedra ulna				1.2	1.9		1	1		2.3	.9		2											
Oscillatoria sp.		2																						
Cladophora glomerata													30%											

TABLE 42.77 (cont)

RIVER NENE — DATE 3.6.1977

STATION	1						2						3											
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Diatoma vulgare	NA	U					2	U						U	E	E	E							
Gomphonema olivaceum			4.7	1.3	3.4																			
Melosira varians													1											
Navicula spp.			.7	.6	.6		1		.2	.7	.4		1											
Nitzschia acicularis			.3	.5	.4																			
palea			1.3	.8	1.0																			
sigmoidea													1											
Rhoicosphenia curvata			.3	.7	.8								1											
Synedra ulna							1		.6	.4	.5													
Cladophora glomerata							50%						30%											
Enteromorpha intestinalis													5%											
Palmelloid green			P	P	P				P	P	P													

TABLE A2.11 (cont)

RIVER NENE DATE 30·6·1977

STATION	1						2						3											
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.	NA	U	2·4	2·2	1·8		NA	U	U	L	L		NA	U	U	1·9	0							
Cocconeis placentula			7·3	1·7	2·6											1·6	0							
Cymbella vertricosa			0	0	·1																			
Gomphonema parvulum			·9	·4	·1											·4	0							
Navicula spp.			·1	·1	0											·1	0							
Nitzschia acicularis			·1	0	0																			
palea			·1	0	0											·9	0							
Rhoicosphenia curvata			1·9	·2	·2																			
Ankistrodesmus sp.			·1	0	0																			
Cladophora glomerata							40%																	
Scenedesmus quadricauda			·1	0	0																			
Palmelloid green			P	P	P											P	P							

TABLE 42 11 (cont.)

RIVER NENE DATE 25·8·1977

STATION	1						2						3											
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cocconeis placentula	NA	NA	5·7	3·1	3·6		NA	NA	U	U	L		NA	NA										
Cymbella ventricosa			0	0	·1																			
Gomphonema parvulum			0	0	1·3																			
Melosira varians			0	0	·4																			
Navicula spp.			0	·1	·1																			
Nitzschia palea			0	·2	·2																			
Rhoicosphenia curvata			·9	·6	0																			
Palmelloid green			P	P	P										P	P	P							

TABLE A2.11 (cont.)

RIVER NENE — DATE 21.9.1977

STATION	1						2						3											
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.	NA	U					NA		F	F	F		NA		L	0	.2							
Cocconeis placentula			7.0	6.4	1.8											3.3	8.6							
Cymatopleura solea			0	0	.1																			
Cymbella ventricosa			.1	.2	.1											.1	0							
Diatoma vulgare			0	.1	0																			
Gomphonema olivaceum			0	0	.1																			
parvulum																2.1	0							
Gyrosigma attenuatum								2																
Melosira varians																1.4	1.9							
Navicula spp.			.1	1.7	.3			3								1.1	.6							
Nitzschia palea			19.6	24.3	21.3			2								5.7	3.0							
Rhoicosphenia curvata			.1	1.7	.4											.2	0							
Synedra ulna			.1	.8	2.3											.1	.1							
Lyngbya sp.								2																
Characium sp.			.1	0	0																			
Cladophora glomerata								5%						5%										
Scenedesmus quadricauda			0	0	.1																			
Almelloid green			P	P	P											P	P							

TABLE 42 11 (cont.)

RIVER NENE DATE 16.11.1977

STATION	1						2						3											
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Caloneis amphisbaena	NA	NA					NA	1	F				NA											
Cocconeis placentula			11.9	19.4	3.2					0	.1				4.3	2.1	.9							
Cymatopleura solea								1																
Diatoma vulgare															.6	1.2	.4							
Fragilaria capucina			.1	0	0										.2	0	0							
Gomphonema augur															0	.1	0							
parvulum			.3	.2	.2					0	.1				0	0	.3							
Gyrosigma attenuatum			0	.1	0			2																
Melosira varians			1.2	1.6	.2										.5	0	.4							
Navicula spp.			.1	.2	0			2						1	1.7	.8	.3							
Nitzschia communis															3.1	5.9	4.3							
linearis								1							0	.2	0							
palea			.2	.1	.2										1.5	2.4	1.2							
sigma								1																
sigmoidea															0	0	.2							
sublinearis															1.8	7.3	3.8							
Rhoicosphenia curvata															.4	.7	1.3							
Synedra ulna			0	0	.1									1										
Oscillatoria sp.								2																
Cladophora glomerata								5%																
Scenedesmus quadricauda			0	.1	0																			
Stigeoclonium sp.			P	P	P					P	P													
Palmelloid green															P	P	P							

TABLE A2.11 (cont.)

RIVER NENE DATE 14.12.1977

STATION	1						2						3											
	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cocconeis placentula	NA	NA	0	0	·1		NA	NA	F	F	F		NA	NA	U	U	U							
Fragilaria capucina			·1	·2	·2																			
Gomphonema parvulum			·2	·2	·5																			
Gyrosigma attenuatum			0	·1	0																			
Melosira varians			·4	4·2	1·2																			
Navicula spp.			·3	·2	·6																			
Nitzschia sigmoidea			0	·1	0																			
Synedra ulna			·1	·2	0																			
Vorticella sp.			P	P	P				P	P	P													

TABLE A2.12

RIVER FOSS	DATE (24.4.1977) 27.5.1977						DATE 22.7.1977						DATE 19.8.1977											
STATION	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Cocconeis placentula	1	NA	1·8	1·1	5·3		NA	NA	·2	0	·8		NA	NA	·3	·2	·5							
Cymbella sp.															0	·2	0							
Diatoma vulgare	2		·3	·6	3·2																			
Gomphonema olivaceum			·1	·6	3·7																			
parvulum															·2	80·0	·8							
Navicula spp.	1		3·2	2·9	1·6										·1	·3	·2							
Nitzschia palea															·3	·5	·3							
Rhoicosphenia curvata	2		6·7	4·6	3·9				0	0	·1				·2	·6	·3							
Synedra ulna	4		3·5	2·1	1·7																			
Characium sp.															2·7	·9	1·2							
Cladophora glomerata	30%																							
Enteromorpha intestinalis	10%																							
Ulvella frequens			P	P	P																			
Palmelloid green									P	P	P				P	P	P							

TABLE 42.73

RIVER DON	DATE (24.4.1977) 27.5.1977						DATE 22.7.1977						DATE 19.8.1977											
STATION	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Gomphonema parvulum	NP	NA	594	63.6	649		NP	NA	83.4	68.9	24.9		NP	NA	5.6	5.9	7.8							
Navicula spp.			.2	.2	.1																			
Nitzschia palea			.3	.7	.6										0	.3	0							
Rhoicosphenia curvata															.2	0	0							
Synedra ulna			.3	.1	.5																			
Characium sp.									5.4	3.2	4.8				3.3	.9	1.7							
Stigeoclonium tenue			P	P	P				P	P	P													
Palmelloid green									P	P	P				P	P	P							

TABLE 42.14

RIVER BRISTOL AVON	DATE (11·7·1977) 8·8·1977						DATE 5·10·1977						DATE 31·10·1977						DATE 30·11·1977					
STATION	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.	NP	NA	·3	·1	0		NP	NA	0	0	·3		NP	NA					NP	NA	U			
Amphora ovalis			1·7	2·2	3·8				·1	1·6	1·4													
Cocconeis placentula			3·4	7·1	1·2				0	1·9	16·0													
Cymbella lanceolata			·6	·2	·5																			
sp.			·2	·7	·2				0	·6	·8													
Fragilaria capucina			·1	0	0																			
Gomphonema parvulum			0	·1	0																	·1	0	
Gyrosigma attenuatum			0	0	·1				0	0	·1											·1	0	
Melosira varians			·6	4·9	1·4				·6	1·2	1·3				·5	·8	·4					·3	·5	
Navicula spp.			3·4	6·5	5·7				0	1·7	2·4											·1	0	
Nitzschia communis			3·8	2·4	1·3																			
linearis															·1	0	·3					·1	·1	
palea			·8	1·3	·4				0	2·8	3·3				0	0	·1					·1	0	
sigmoidea									0	0	·1													
Rhoicosphenia curvata			·2	·1	·4				0	·2	·1													
Synedra acus				·1																				
ulna			·1	·2	0				·1	0	·2				0	0	·1							
Scenedesmus quadricauda			·1	·2	0																			
Palmelloid green			P	P	P																			

TABLE A2.15

RIVER SOUTH DRAIN	DATE (11.7.1977) 8.8.1977						DATE 5.10.1977						DATE 31.10.1977						DATE 30.11.1977					
STATION	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M	R	P	S	S	S	M
Achnanthes sp.	NP	NA	0	.2	0		NP	NA	F	F	F		NP	NA	F	F	F		NP	NA	0	1.8	0	
Cocconeis placentula			.1	0	.2																.1	.3	0	
Diatoma vulgare																					.3	.2	0	
Fragilaria capucina																					0	.4	0	
Gomphonema parvulum			.3	.5	.2																0	2.2	.1	
Melosira varians																					8.6	3.2	.2	
Navicula spp.			4.6	1.2	3.6																.1	.6	.1	
Nitzschia communis																					0	1.7	0	
palea			1.6	.5	1.9																0	.7	.1	
sublinearis																					.5	.4	.1	
Rhoicosphenia curvata			.2	0	.3																.2	1.0	0	
Synedra ulna																					.6	[illegible]	.3	
Characium sp.			.2	0	.2																			
Chlorococcum sp.			P	P	P																			
Gongrosira sp.			P	P	P																			
Scenedesmus quadricauda			.1	0	0																			
Palmelloid green			P	P	P																P	P	P	

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