THE CLASSIFICATION AND PREDICTION OF MACROINVERTEBRATE COMMUNITIES IN BRITISH RIVERS

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Introduction

Classification schemes which delimit zones along rivers, using the dominant fish species, were developed in Europe and North America for fishery management purposes many years ago (Hawkes 1975). Within Great Britain, modified versions of these schemes failed to gain general acceptance. Nevertheless a river classification system based on zones or sites would have widespread application. We chose the macroinvertebrate fauna for the development of a sensitive and practical system for site classification because of the wide variety of species found at most sites and because of their differing environmental requirements.

There are a number of advantages in attempting to pioneer this type of work on British rivers. In particular, Britain has fewer species of macroinvertebrates than mainland Europe and keys are available for the identification to species of most taxonomic groups. It also has a fairly wide range of rivers within a limited area as a result of its varied geology and topography. A further advantage is the availability of physical and chemical data for most British rivers.

In 1977 a team of invertebrate zoologists at the River Laboratory started work on what is now known as the 'River Communities Project'. Dr D. Moss of the Institute of Terrestrial Ecology also joined the team to provide the necessary specialist advice on computing and data analysis. The project was conceived as a practical response to a need for greater knowledge and understanding of the variation in running-water sites and their macroinvertebrate communities in Great Britain. It also represented a rewarding development in FBA research, involving extensive liaison and collaboration with biologists in the Regional Water Authorities of England and Wales and also the Scottish River Purification Boards. Although a classification of sites on British rivers has application within the water industry for cataloguing the biological resources of each watercourse, there are additional uses. An objective classification would enable the Nature Conservancy Council to reappraise the range of rivers scheduled in the Nature Conservation Review (Ratcliffe 1977). Beyond this, we believe that a classification will be of value to the scientific community in allowing studies in different rivers to be brought together and seen in a new perspective, thereby leading to a greater understanding of river ecology.

In addition to the development of a classification, the project has a second objective: to examine relationships between the physical and chemical features of sites and their biological communities with a view to determining whether easily-made measurements of environmental variables can be used to predict whether particular macroinvertebrates should be expected to be present. This objective is of relevance not only to those concerned with the day-to-day problems of river management but also to scientists interested in basic questions about the structure and functioning of benthic communities.

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The sampling programme

Initially, 268 sites on 41 British river systems were sampled (rivers 1–41 in Fig. 1) to provide information for a series of preliminary classifications (Wright, Moss et al. 1984; Furse, Moss et al. 1984). More recently, we have sampled at additional sites and this has led to a new 370-site classification using information on 61 river systems. The rivers to be studied were selected to include as wide a range of environmental conditions as possible and to represent all parts of the country. Choice of sites on each river reflected the need to sample more intensively near the source than further downstream where environmental changes are more gradual. Polluted sites were excluded to ensure that correlations between the macroinvertebrate communities of sites and their environmental features could be examined without additional complications.

Qualitative sampling with a standard FBA pond-net was selected as being the most versatile technique for dealing with the range of depth, width, water velocity and substratum characteristics likely to be encountered. In view of the large number of biologists involved in collecting samples, the validity of this approach was first tested in a field trial on the River Axe in south-west England (Furse et al. 1981). Three members of the team each took 2 samples of 3 minutes duration at each of 4 sampling sites. A comparison of the number of families and species caught indicated statistically significant differences between the counts recorded by different team members. Despite this, when data were examined at species level, the statistical methods later to be used in the main analyses successfully placed all samples from any given site into a discrete group. Similar variation in the rate of accumulation of taxa was anticipated in those participating in the full sampling programme throughout Great Britain. However, use of 3 sampling occasions to acquire a more comprehensive species list, coupled with the proven ability of the statistical techniques to distinguish between the River Axe sites when more than one person was involved in sampling, provided justification for the use of the pond-net technique.

Biologists within the water industry sampled the majority of the 370 sites, using guidelines provided by the FBA team. Normally a 3-minute

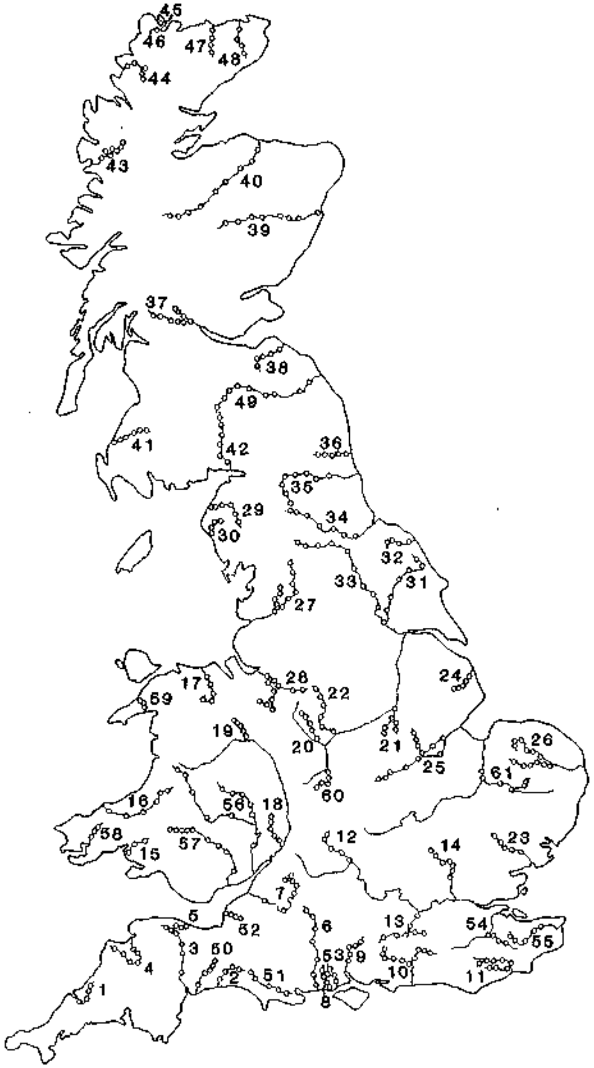

FIG. 1. The 61 river systems sampled, with sampling sites indicated by circles. 1 Camel, 2 Axe (SWWA), 3 Exe, 4 Torridge, 5 Avill, 6 Hampshire Avon, 7 Bristol Avon, 8 Avonwater, 9 Itchen, 10 Arun, 11 Rother, 12 Evenlode, 13 Wey, 14 Lee, 15 Gwendraeth Fach, 16 Teifi, 17 Clwyd, 18 Leadon, 19 Perry, 20 Blithe, 21 Devon, 22 Dove, 23 Colne, 24 Great Eau, 25 Welland, 26 Yare, 27 Ribble, 28 Weaver, 29 Derwent (NWWA), 30 Ehen, 31 Derwent (YWA), 32 Esk, 33 Ouse (YWA), 34 Tees, 35 Tyne (NWA), 36 Wansbeck, 37 Forth, 38 Tyne (FRPB), 39 Dee, 40 Spey, 41 Stinchar, 42 Annan, 43 Carron, 44 Inver, 45 Balnakeil, 46 Durness, 47 Halladale, 48 Thurso, 49 Tweed, 50 Otter, 51 Frome, 52 Axe (Wessex WA), 53 Lymington, 54 Beult, 55 Great Stour, 56 Wye, 57 Usk, 58 Eastern Cleddau, 59 Dwyfach, 60 Blythe, 61 Little Ouse (AWA).

pond-net sample was taken in spring, summer and autumn, and the samples were then sent to the FBA River Laboratory for sorting and identification. Most macroinvertebrates were identified to species using the available keys (Armitage et al. 1979). An indication of the abundance of each family of macroinvertebrates in each sample was also recorded. Further information on the design of the sampling programme, together with field sampling and laboratory procedures may be found in Furse et al. (1981) and Wright, Moss et al. (1984).

A species list of 80–90 taxa was typical for many sites, but 148 taxa were recorded at one site. Although the species lists cannot be regarded as complete, they do provide a good basis for site classification.

Physical data were also recorded at each site when samples were taken, and further information was acquired from maps and other published sources (Wright, Moss et al. 1984). Features used included distance of site from source, slope, altitude, discharge, stream width and depth, latitude, longitude and measures of water velocity, substratum type and air temperature. Annual mean values were obtained for a number of chemical variables including pH, dissolved oxygen, total oxidized nitrogen (nitrate + nitrite), chloride, dissolved orthophosphate and total alkalinity. A majority of sites had coincident biological and chemical sampling points but others did not; in the latter case chemical data were taken from the nearest site for which records existed.

Ordination of sites

Ordination is a technique which can be used to plot sites on one or more axes such that those with many species in common are close together but those with very different communities are well separated. The scores for each site on each axis are derived from the species which occur at each site, using objective mathematical techniques. The method of ordination chosen was *detrended correspondence analysis* (Hill 1979a), a procedure which compares favourably with alternative methods (Gauch, Whittaker & Singer 1981). A practical example of this technique (Fig. 2) illustrates that the rivers Exe and Great Eau may be distinguished by their macroinvertebrate communities and also that progressive changes occur in the species recorded at successive sites along individual river systems. Further examination of the position of sites on this plot suggests that site scores for individual axes may be correlated with environmental gradients. This proved to be the case using the data-set for rivers 1–41 (268 sites), with species identification for each site. On Axis 1 the highest correlation was found with a measure of substratum particle size ($r = 0{\cdot}78$). A high correlation was also obtained with total alkalinity ($r = 0{\cdot}74$). Sites with low Axis 1 scores tended to have a coarse substratum and low alkalinity whilst those with high

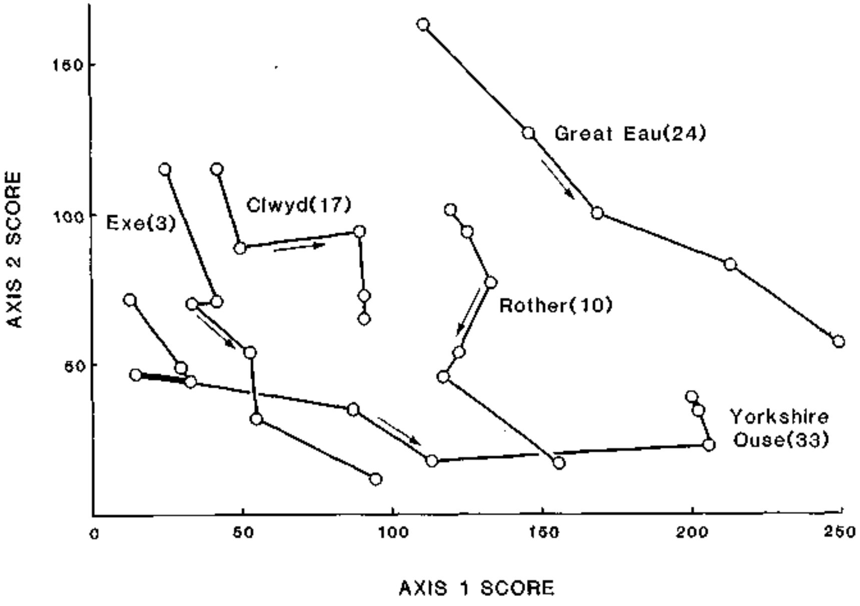

FIG. 2. An ordination plot of successive sites down five contrasted rivers. Arrows indicate the direction of flow.

scores had a finer substratum and high alkalinity. The former features were usually observed in upland mineral-poor rivers in the north and west which contrasted with the lowland mineral-rich rivers in the south and east. On Axis 2, the highest correlations were found with features which indicated position along the river including, for example, logarithm of distance from source ($r = -0{\cdot}78$) as measured on a 1:250000 map.

Fig. 2 emphasizes these features by showing successive sites down five contrasted rivers. The R. Exe (river no. 3 in Fig. 1) and R. Clwyd (17) are given as examples of upland mineral-poor rivers with low Axis 1 scores which contrast with the R. Rother (tributary of the R. Arun, 10) and R. Great Eau (24) from lowland England. The Yorkshire Ouse (33) has more extensive changes in character along its length. Upstream sites with a coarse substratum drain the Pennines (low Axis 1 scores) whilst further downstream the river becomes depositing and in consequence there are substantial changes in the macroinvertebrate community which give rise to high Axis 1 scores.

The pattern in which the first axis tends to reflect river type, and the second axis correlates with position downstream, is usually repeated

even if the ordinations are based on single seasons' data or on identifications to family level only (Furse, Moss et al. 1984). Correlations between site scores and 28 environmental variables were investigated in early analyses (Wright, Moss et al. 1984), and further variables have been examined more recently. Although correlations do not provide direct evidence of the environmental features which affect community structure, they can offer useful guidelines when planning future work designed to investigate factors which determine community structure and function.

Classification of sites

Hierarchical methods for classification of community data fall into two broad categories, those in which sites are progressively combined into groups on the basis of similarity (agglomerative techniques) and those in which all sites are considered together at the outset and then divided into smaller and smaller groups (divisive techniques). The relative merits of the two approaches have been considered by Gauch & Whittaker (1981), who conclude that TWINSPAN (Hill 1979b), the divisive technique used in this study, is usually the best method when the dataset is large and complex. This method classifies both samples and species and also constructs a key to the sample classification by listing 'differential' species which are particularly diagnostic of each division in the classification. This key can then be used to classify new sites without the need to reclassify the entire data-set.

The division of the 268 sites (species-level identification) into 16 site groups is given in Fig. 3a. For detailed information on the composition and site characteristics of each group, refer to Wright, Moss et al. (1984). Essentially, the progression from upland to lowland sites takes place from left to right. Macroinvertebrates which are characteristic of the upland groups include stoneflies, and many genera of mayflies, caddis and true flies. In contrast, the lowland groups are dominated by worms, molluscs and additional genera of true flies together with flatworms, leeches, crustaceans and water bugs. Despite these substantial changes in species composition between groups, the mean number of taxa found at the sites comprising each group remained fairly stable (Fig. 3b). The most notable exceptions were found in an upland group of 28 sites confined to northern England and Scotland which had a restricted fauna ($\bar{x}$ = 55 taxa) and 8 species-rich sites ($\bar{x}$ = 122 taxa), most of which occurred in south-west Wales.

Colonization of fresh water by insects is generally regarded as having taken place from the land, whereas the majority of other groups are believed to have invaded fresh water from the sea via brackish water. The greater preponderance of the insects in upland rivers can be observed in

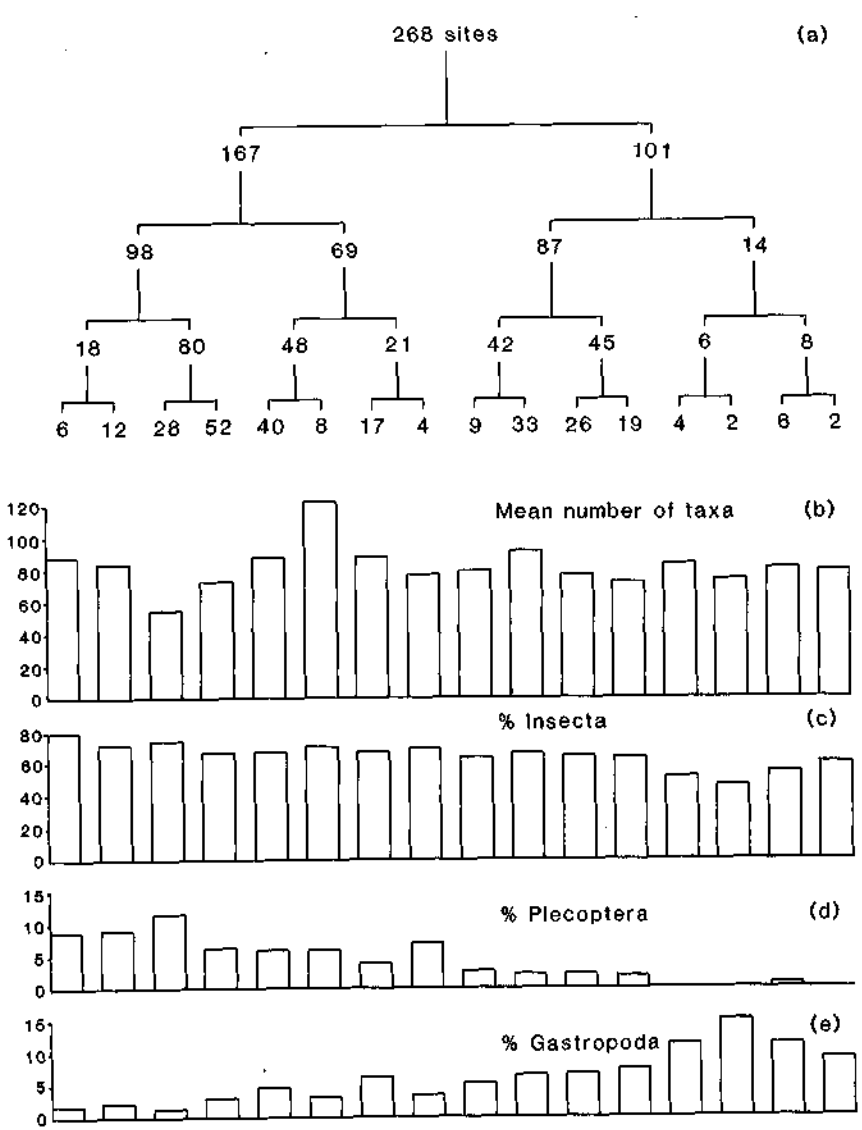

FIG. 3. The species-level classification of 268 sites. (a) Dendrogram showing the division of sites between the 16 TWINSPAN groups. (b) Mean number of taxa per site in each TWINSPAN group. (c) % of taxa recorded within each TWINSPAN group which are Insecta. (d) % Plecoptera. (e) % Gastropoda.

this data-set (Fig. 3c) and this pattern of decreasing species richness and relative importance from upland to lowland groups is particularly obvious in the Plecoptera (Fig. 3d). A trend in the opposite direction may be seen in the Gastropoda (Fig. 3e).

Furse, Moss et al. (1984) discuss possible applications of 16 different classifications, including the merits of a classification based on identification of the fauna to family-level only. The advantage of such a system is that it involves less effort on the part of the user when sampling and classifying new sites. However, it is important to know how classifications based on species and family identifications differ, and whether one has greater validity than the other. The higher information content of the species-based classification might be expected to make it superior, but an independent means of checking this viewpoint is required. If the fauna at a site is strongly influenced by the physical and chemical environment, then the 'best' classification should be the most efficient at grouping together sites which have similar environmental features.

Prediction of site groupings from environmental features

Using *multiple discriminant analysis* (MDA), we investigated whether environmental data could be used to predict the group to which a site belonged and hence the fauna likely to be present (Wright, Moss et al. 1984). This method produces predictive equations, based on environmental variables, which give the best fit between the site groupings established in the biological classification and the environmental data. For a given set of environmental data the probabilities are calculated that a site of those characteristics will belong to each of the groups in the biological classification. We regarded a prediction as correct if the most probable group on environmental grounds was the same as that to which the site had been assigned in the classification.

When 28 environmental variables were used to assign each site to one of 16 groups in the 268-site species-level classification, 76·1% of them were placed correctly (Table 1). In a further 15·3% of sites the correct group was given as the second most probable, suggesting that many of the incorrect predictions were 'near misses'. Predictions obtained for

TABLE 1. Percentage of sites assigned to the correct site grouping using 28 environmental variables (268-site classifications).

Classification		*Number of site groups*			
		2	4	8	16
Species	3 seasons	91·4	84·3	79·1	76·1
,,	autumn only	91·4	83·6	75·4	69·0
BMWP families	3 seasons	92·9	79·5	69·8	60·1
,,	spring only	88·8	70·9	59·7	46·6

additional classifications are also presented in Table 1. The species-level classification based on the single-season sampling which gave the best fit (autumn) allowed 69·0% of sites to be assigned to the correct group. From this it was concluded that there was value in sampling in three seasons to obtain a more comprehensive species list.

Additional classifications, based on the identification of the fauna to family only, were also examined. A Biological Monitoring Working Party (BMWP) set up by the National Water Council and the Department of the Environment devised a system for the assessment of the biological quality of rivers based on the occurrence of a restricted list of families of macroinvertebrates (National Water Council 1981). The fit between environmental data and site groupings derived from the presence or absence of BMWP families did not match equivalent levels achieved using species-based classifications (Table 1). However, a substantial proportion of the sites were still assigned to the correct group and the time saved by identification to family level only is considerable. Hence a second classification based on BMWP families for use within the water industry could have some practical advantages.

These results demonstrate the fit between the biological and environmental attributes of the 268 sites. A more rigorous test of predictive ability is to take unclassified sites and assign them to groups. Forty test sites, selected at random from the 268, were classified using a biological key and MDA equations developed for a classification of the remaining 228 sites. Only 50% of the sites were assigned to the same group using biological and environmental criteria compared to 76·1% of sites in the original test involving all 268 sites. This may seem disappointing but in practice there are several deficiencies in the use of the agreement between biological and environmental placements in assessing predictive success.

One important limitation is that the predictions, whether correct or incorrect, do not show the relationship between the observed fauna at the test site and the fauna at the sites in the group to which the test site was predicted. In practice, test sites were often similar in faunal characteristics to several groups (Furse, Moss et al. 1984). It was shown that the similarity between test sites and the groups in which they were placed by the biological key or by environmental criteria was always close to the maximum achievable. Thus it appears that expressing success by the number of sites 'correctly' assigned to a group can give a misleadingly poor impression of the accuracy with which the fauna can be predicted. In fact, prediction of site grouping from biological or environmental data, though useful for site classification, is only a step towards the prediction of species occurrence at sites with known environmental characteristics. Further progress is now being made in this important area.

Current developments in classification and prediction

Recently a new classification has been developed, using species data for the 370 sites shown in Fig. 1. Unlike the preliminary classification (Fig. 3), the new one has been taken to 30 site groups as a consequence of the wider range of sites and because this decision appears to be justified on ecological grounds. The percentage of the 370 sites assigned to the 'correct' site group using environmental data has also improved marginally after the addition of further variables. New procedures have been developed for predicting the probability of occurrence of individual species at sites with known environmental data. Predictions at a series of test sites have been assessed by sampling for macroinvertebrates with the standard FBA pond-net technique. The results are encouraging and fulfil expectations. At present they are in an unpublished report but are being prepared for publication.

The initial production of a site classification and the subsequent attempts at prediction of site groupings and then species using environmental data were undertaken on a mainframe computer. To make both the classification and the facilities for prediction more accessible they are now being transferred to a microcomputer. A manual is also being prepared to allow other biologists to test the procedures and assess their practical value.

The extent to which the classification and prediction facilities are used will depend greatly on the time and effort required to classify sites or predict the fauna, and the value of the results obtained. Where site classification based on species identification is impractical, there is a need to look for worthwhile alternative procedures. Classifications have been developed from family data, but assignment of sites to groups using environmental data has been less successful than for the species classification. A possible alternative to a classification using family data is to retain the classification based on species, with its high predictability, and construct a second biological key which relies upon family-level identifications only. Although some misclassifications would result, the benefits of avoiding the need to compare results from separate classifications are considerable. This approach is now being assessed.

Prediction of the fauna from environmental data has many practical applications unrelated to site classification, but its usefulness depends on the ease with which the relevant environmental data may be acquired. Over 30 environmental variables were used for many predictions but subsequent analyses using only 11, or even 5, variables have provided valuable predictions of species at the test sites examined so far.

The classification still excludes small streams, typically less than 5 km from the source, and sites on some of the larger British rivers. These are now being added by a further sampling programme. After a period of critical assessment of the present classification and prediction system on microcomputer, the new sites will be included and further modifications and improvements made as required.

Further uses of project data

The information which has been obtained on the species composition and environmental features of a wide range of sites throughout Great Britain has many other uses.

In 1980 the National Water Council organized a survey of water quality in England and Wales (National Water Council 1981) which included a new method, the BMWP score system, for the assessment of biological quality. The performance of the new score system was examined using data from 268 unpolluted sites (Armitage et al. 1983). The BMWP system allocates a score in the range 1 to 10 to each family such that those with a low tolerance to organic pollution are given a high score and vice versa. Scores based on the families present together with the Average Score Per Taxon (total score divided by number of families) were assessed with respect to season, sampling effort and type of site. Attempts were made to predict the Average Score Per Taxon to be expected at unpolluted sites, using environmental data, in order to provide target values for sites currently polluted. Further developments, including the prediction of families at unpolluted sites should also be possible in the future.

The 370 sites for which we have lists of macroinvertebrates provided 587 taxa for site classification. Of the non-insect groups, water snails (29 taxa), bivalves (20), true worms (54) and crustaceans (16) were dominant. The insect groups which yielded most taxa were mayflies (34), stoneflies (26), water bugs (24), water beetles (88), caddis (87) and true flies (161). The frequency of occurrence of these 587 taxa at the 370 sites is notable (Table 2). Forty-one taxa were recorded at more than 50% of the sites but 354 taxa were found at less than 6·25% of sites. The potential for the invertebrate community to respond to variations in environmental conditions is therefore very substantial. In practice the total number of taxa recorded at the 370 sites exceeded 700. They included 66 species of water mites which have been excluded from recent classifications due to the specialist knowledge required for their identification. Additional macroinvertebrates which could not always be identified to species were placed in 'species groups' for the purposes of the classification in order to maintain consistency between sites.

TABLE 2. Frequency of occurrence of 587 macroinvertebrate taxa at 370 running-water sites.

Number of sites	*% of sites*	*Number of taxa*
>185	>50%	41
93–184	25–50	57
46–92	12·5–25	70
23–45	6·25–12·5	65
<22	<6·25	354

Several species have been recorded for the first time in Britain, including a chironomid midge (Furse, Armitage et al. 1984), and new characters have been found to help separate the ephemeropteran nymphs of two species in the genus *Baetis* (Armitage et al. in press). Many new site records have been obtained for macroinvertebrates, even in the Plecoptera, whose general patterns of distribution are well-established (Bird 1983). The species records for all macroinvertebrate groups will be published as a series of distribution maps in due course to make the information easily accessible. The availability of environmental data for each site means that it should also be possible to determine and compare the known environmental range of each species. The number of species recorded at each site has been examined in relation to selected environmental features (Wright, Armitage et al. 1984) and further analyses are planned.

This project has focused on the macroinvertebrate fauna of sites on British rivers, and during the same period the Nature Conservancy Council has been attempting to classify sites using macrophytes (Holmes 1983). Close liaison has ensured that some rivers were sampled for both macroinvertebrates and macrophytes to allow direct comparison between the two approaches.

The future

Biologists in many European countries recognize the need to describe and categorize the invertebrate communities in a range of unpolluted river systems to provide a base of reference from which to assess pollution in other rivers (De Pauw & Vanhooren 1983). One approach for gathering the data necessary for a classification of watercourses for the European Community has already been outlined (Persoone 1979). Classification of sites on British rivers is clearly a less formidable task than a similar exercise for rivers on mainland Europe. Nevertheless, many of the techniques used in this project are relevant, as are lessons learnt on the value of species versus family identifications. A collaborative exercise currently under way with scientists in the Basque provinces of northern Spain may show whether these classification and prediction procedures can be adapted and applied to a new series of river systems in Europe.

So far the emphasis has been on answering the questions 'what?' and 'where?'. A further step has been taken in establishing correlations between environmental features and the type of invertebrate community. It is now time to move on from mere correlation to a clearer understanding of 'how?' and 'why?' (Le Cren 1981). How do macroinvertebrate communities respond to man-induced changes such as water abstraction, tree felling in the catchment or organic pollution? How and why does community function change? These are exceedingly complex questions, and research which explores mechanisms will be required for progress in this field (Clarke 1984). There are many opportunities for observing at first hand the changes in community structure and function which accompany man-induced changes in running waters. It is therefore possible to have a practical input to applied problems and at the same time provide some insight into more basic questions concerning factors which shape the structure and functioning of macroinvertebrate communities. In future it will be possible to use the prediction facilities to attempt to predict the outcome of particular environmental change. Opportunities to examine rivers before, during and after the change should be used to test the validity of the predictions.

In view of the complexity of the subject it will also be necessary to undertake basic research to clarify lines of investigation highlighted by applied problems. The testing of hypotheses may involve the use of experimental streams and field manipulations in natural streams. Stream ecology has reached an exciting phase and many ideas of relevance to community ecology are now being discussed and tested. In the next few years there should be developments in the understanding of community structure and function which have practical value in the management of running-water ecosystems.

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