A comparison of some classification methods used to determine benthic macro-invertebrate species associations in river survey work based on data obtained from the River Ely, South Wales

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SUMMARY. The results of a survey of the macro-invertebrates of the polluted River Ely, South Wales, are used as a basis for comparing several classification methods which have been used previously in river survey work to determine species groupings. The methods compared are product-moment correlation (clustered by the nearest neighbour technique), Kendall's *tau* coefficient (clustered by the nearest neighbour and average linkage techniques), and Squared Euclidean-Distance coefficient (clustered by nearest neighbour and Ward's techniques). The species groupings determined by these methods were influenced both by the association coefficient and the technique used to cluster it. Some species were grouped together by all or most of the methods. The ecological validity of these robust groups is examined. A clear recommendation regarding the most appropriate method is frustrated by incomplete knowledge of the ecological requirements of most of the aquatic macro-invertebrates used in the data-set. However, Kendall's *tau* coefficient clustered by the average linkage technique appeared to produce ecologically meaningful species groups. Product-moment correlation was also reasonably successful and since it is based on absolute abundance data whereas Kendall's *tau* coefficient is based on relative abundance data, the use of the two together is recommended for determining robust groups.

Introduction

Throughout the present century there has been a steady development of methods for summarizing the large quantity of biological data obtained from river surveys. These methods, recently reviewed by Wilhm (1975), Hawkes (1977) and Hellawell (1977a, b, 1978), usually result in the production of biotic and diversity indices. They are intended to codify the response of groups of

organisms to changes in water quality and have been developed principally to detect and assess pollution. Such methods are essentially pragmatic in their conception, much of the information contained within the samples remains unused, and only rarely does their use further our knowledge regarding the ecology of riverine species. Now that computers are more readily available, greater use can be made of the range of classification and ordination methods for determining species groups within large data-sets (Greig-Smith, 1964; Clifford & Stephenson, 1975; Green, 1979). Since these methods make greater use of the information content of the

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samples, they are potentially a more sensitive way of identifying environmental change and ecological knowledge is likely to be advanced by their adoption. Edwards, Hughes & Read (1975) and Hamer & Soulsby (1980) showed that the objective establishment of species groups using multivariate analysis could provide a more reliable and sensitive method for identifying environmental discontinuities, especially those induced by pollution, than the use of biotic and diversity indices. However, the attractiveness of multivariate analysis for this purpose is reduced because many multivariate techniques exist and there is evidence (Williams, 1971; Pinkham & Pearson, 1976; Clarke, 1977; Hellawell, 1978) that application of different techniques to the same data-set is likely to produce different groupings of species. This clearly complicates comparison between studies where different methods have been applied and impedes wider acceptance of the species groups identified in any one study as being reliable and sensitive indicators of particular environmental conditions.

The objectives of the present study were to establish the extent to which the application to the same data-set of some of the classification methods, which have been used previously by freshwater ecologists to determine benthic macro-invertebrate species groups, would produce different groupings of species, and to clarify, if possible, the appropriateness of the methods for producing ecologically meaningful species groups.

The raw data used for the comparison were obtained during a macro-invertebrate survey of the polluted River Ely, South Wales, in August 1973.

Description of the R. Ely

The river (Fig. 1) rises about 366 m above mean sea level in moorland on the southern edge of the South Wales coalfield just west (SS 990903) of Williamstown and flows south-easterly for about 45 km before entering the Bristol Channel at Cardiff. The total catchment area is 169 km².

The river above Llantrisant has cut through rock of the upper coal measures and the valleys are relatively steep sided. The mean river gradient between S1 and S4 (Fig. 1) is 9.1 m km⁻¹. Downstream of Llantrisant the river

crosses the plain of the Vale of Glamorgan composed chiefly of drift deposits (boulder clay, sands and gravels). In this region the gradient is much less being 2.0 m km⁻¹ between S4 and S9.

Flow is continuously recorded at two sites (Fig. 1). Flows for the year October 1972 to September 1973 at the upper site ranged from $9.5 \times 10^3 \text{ m}^3 \text{ d}^{-1}$ (August) to $3819 \times 10^3 \text{ m}^3 \text{ d}^{-1}$ (November) with a mean of $102 \times 10^3 \text{ m}^3 \text{ d}^{-1}$. Corresponding flows at the lower site were $54 \times 10^3 \text{ m}^3 \text{ d}^{-1}$ to $11,456 \times 10^3 \text{ m}^3 \text{ d}^{-1}$ with a mean of $301 \times 10^3 \text{ m}^3 \text{ d}^{-1}$.

Sewage and industrial discharges

The river upstream of S1 was affected by the dumping of domestic rubbish, particularly vegetable refuse. A major decline in water quality occurred between S1 and S2 caused principally by the discharge of ammonia and inert particulate matter, and occasionally phenols and thiocyanates, from the Coedely Coking Plant. Between S2 and S4 water quality remained poor because of the effluent from an overloaded sewage works. Heavy metal contamination, especially by copper, also occurred in this reach. Downstream of S4 the river was affected by industrial sources of biodegradable organic matter and upstream of S5 the entry of the Afon Clun brought in coal particles. Between S6 and S7 the river received the effluent from an overloaded sewage works. From S7 to S9 water quality improved, the river flowing through an agricultural region until it reaches Cardiff and receiving few discharges apart from sewage effluents and land drainage. The Nant Mychudd is unpolluted for most of its length but receives an industrial effluent upstream of S3.

Site selection and sampling method

Sites were selected in relation to accessibility and known sources of pollution (Fig. 1). Riffles were sampled partly to reduce variability between sites and partly because they generally support a more diverse benthic macro-invertebrate fauna than pools (Hynes, 1970) and hence have greater information content. It is likely, therefore, that changes in the composition of the riffle fauna provide a more sensitive measure of environmental differences between sites. Riffle reaches predominated upstream of Llantrisant but were less frequent downstream where deposition of particles generally prevailed.

Five or ten samples of the benthic macro-invertebrate fauna were collected at roughly equal intervals across the width of the river at each site. Transect sampling has been recommended by Cummins (1962) as providing more information per unit sample effort than other sampling procedures. Each sample was collected by means of a Surber-type sampler which covered an area of 0.1 m^2 and which had a net of $400 \mu\text{m}$ diagonal pore-aperture (24 mesh cm^{-1}). Edwards *et al.* (1972) concluded that this mesh size was the best for general sampling purposes of the three meshes they compared in the near-by River Taff system.

Ten samples were collected at sites where artificial-substrate samplers were also being used. A comparison of the results obtained using the different sampling methods will be given elsewhere.

Five minutes were devoted to the collection of each sample after preliminary work at S1 and S9, using one minute sequential sampling, had shown that sampling for this length of time accounted for between 90–99% of the total macro-invertebrate abundance obtainable by the mesh size used and 96–100% of the species present in each part of the river bed sampled.

All samples were collected over the period 16–17 August and the animals preserved in formaldehyde for later examination. Larger animals were removed from whole samples but a standardized sub-sampling procedure (Elliott, 1977, p. 135) was adopted for smaller animals. Additional samples were collected several times during August and early September from all sites. These were used to provide live chironomid larvae for rearing to adults. In this way, all the numerically important larvae were identified to species.

Physical description of sites

Morphometric details, current velocity measurements and substrate samples were all collected a week after the collection of the macro-invertebrate samples. The results are summarized in Table 1.

At least fifteen depth measurements were made at equally spaced intervals across the river at each site.

Current velocity was determined by means of a small Ott current meter held, (a) just below the water surface, and (b) just above the substratum,

at a quarter, half and three-quarters of the distance across the river.

Substrate samples were collected by means of a cylinder with a toothed rim which was forced into the bed of the river. The cylinder delimited 0.1 m^2 of bed and substrate to a depth of approximately 10 cm was transferred into a conical canvas bag, terminated by a 1-l plastic bottle, which was attached around a large opening in the downstream side of the cylinder. One sample was collected at each site from a region of the river bed subjectively assessed to be typical of the riffle. Each sample was dried and approximately 500 g at a time were shaken for 10 min through a nest of nine 20-cm diameter sieves of 16, 8, 4, 2 and 1 mm, and 500, 250 and $63 \mu\text{m}$ mesh, respectively, by means of a mechanical sieve-shaker (Cummins, 1962). Large stones were weighed separately.

Chemical description of sites

Water quality data were provided by the Welsh Water Authority for eight stations on the R. Ely (Fig. 1) for the period January 1972 to December 1973. These data are summarized in Table 2. Unfortunately, the stations used by the Authority for routine chemical sampling were unsuitable for macro-invertebrate sampling and therefore Table 2 provides only a general description of the quality of the water at the sites sampled for macro-invertebrates.

Data analysis methods

Objective techniques for the determination of species groups generally involve two steps. Firstly, a coefficient of association (sometimes dissociation) between each pair of species is calculated and secondly, the resulting matrix of coefficients is subjected to a clustering strategy which produces groups of species. The measures of association (or dissociation) used in the present study were chosen because they are widely referred to in the literature and because they have been used previously by river ecologists (Edwards *et al.*, 1975; Hughes, 1975; Ghetti & Bonazzi, 1977; Pollard, 1977; Brooker & Morris, 1980; Scullion & Edwards, 1980). These measures were product-moment correlation, Kendall's 'tau' rank correlation and, as

a distance coefficient, Squared Euclidean-Distance. Measures were selected which required the use of quantitative data because examination of the raw data indicated that most of the numerically important species in the R. Ely occurred at most of the sites and therefore qualitative (presence-absence) data would not discriminate between the species. This view was confirmed in an analysis of the data using Jaccard's coefficient of similarity (Jaccard, 1912).

Although the measures selected used quantitative data, product-moment correlation and Squared Euclidean-Distance are based on the absolute abundance of each species while Kendall's rank correlation method is based on relative abundance.

Most previous workers (Edwards *et al.*, 1975; Hughes, 1975; Pollard, 1977; Scullion & Edwards, 1980) who have applied correlation methods to riverine macro-invertebrate data have grouped species on the basis of the degree of association between them (significance of the correlation coefficient). This is permissible if samples are collected at random and if the correlated measures are normally distributed (Greig-Smith, 1964). However, because the macro-invertebrate data resulting from the R. Ely survey did not satisfy this requirement the correlation coefficient was used simply to describe the presence of association between sets of variables. Its use in this context does not require assumptions to be made of the statistical distribution of the variables and it was unnecessary to transform the data prior to calculating the product-moment correlation coefficient. This is advantageous because transformed data may not be so easily interpretable biologically even though a transformation may be statistically appropriate (Gertz, 1978; Meeter & Livingston, 1978). Species restricted to a few sites only are likely to be associated on the basis of their joint absence from the majority of sites. Such associations have doubtful ecological significance because different reasons could account for the absence of species from a particular site. We therefore excluded from the data matrix those species which occurred at fewer than four sites. There was no evidence that species restricted to four sites were associated on the basis of joint absences. Where a species occurred at more than four sites, any zero values were included in the matrix.

Data treated in exactly the same manner were used in both Kendall's rank correlation procedure and in the calculation of the Squared Euclidean-Distance coefficient. Although Brooker & Morris (1980) used Spearman's rank correlation coefficient, Bullock (1971) clearly preferred Kendall's *tau* coefficient partly because differences in rank are treated arithmetically whereas Spearman's method treats rank differences in a geometric manner which tends to over-emphasize major differences in rank. Siegel (1956) also considered Kendall's coefficient preferable to Spearman's when dealing with small sample sizes because it has a distribution close to a normal one for sample sizes as low as nine. Kendall's *tau* coefficient was therefore preferred in the present comparison. Tied ranks were dealt with using the mid-rank method (Kendall, 1955).

The Squared Euclidean-Distance coefficient was the only one of the three selected which measured the degree of dissociation between species (Clifford & Stephenson, 1975). The resulting data matrix was clustered using Ward's method of hierarchical grouping (Wishart, 1975) and also the nearest neighbour method. Ward's method is most appropriately used with distance measures and therefore the nearest neighbour method was also used because of its wider applicability. Jardine & Sibson (1968, 1971) believed that this was the only method of clustering that met all the mathematical criteria they suggested should be applied to any method of cluster analysis when assessing its suitability. For this reason the nearest neighbour method of hierarchical grouping was also applied to the product-moment correlation and to Kendall's *tau* correlation measures of association. However, nearest neighbour grouping is prone to the chaining effect (Shepherd & Willmott, 1968) in that species tend to join existing clusters because they resemble one member of the cluster although they may be very different from other members. The species associations resulting from the use of the various clustering techniques were examined carefully to make certain that the species forming the association were closely interlinked and that species were not being incorporated into the clusters by chaining. No chaining was observed in these clusters.

Despite Jardine & Sibson's (1968, 1971) views, average linkage (unweighted pair-group) clustering was applied to Kendall's *tau* coefficient.

TABLE 1. Position of macro-invertebrate sampling sites and their physical description. Measurements of channel width, water depth and current velocity were made on 23 August 1973 when substrate samples were also collected. Stream order (Strahler, 1964) and stream link magnitude (Shreve, 1966) are based on channels marked on a 1 : 50,000 scale map.

Site (Grid Ref.)	Distance from source (km)	Altitude above mean sea level (m)	Gradient (m km ⁻¹)	Stream order	Stream link magnitude	Width of channel (m)	Average depth of water (cm)	Average current velocity at surface and just above substratum (m s ⁻¹)	Substrate		Bankside and aquatic vegetation
									Proportion passing through 16-mm sieve (%)	Proportion passing through 1-mm sieve (%)	
1. Upstream of confluence with Nant Llanilid (ST 010868)	5.6	112	7.3	4	10	4.0	10	0.23 0.15	11	1.2	Completely shaded by broad- leaved trees. Some aquatic mosses.
2. Downstream of Coedely Coking Plant (ST 022851)	8.6	79	19.8	4	19	8.4	6	0.25 0.21	3	0.6	Partly shaded by broad- leaved trees.
3. Nant Mychydd (ST 038842)	—	60	6.4	4	13	4.5	5	0.51 0.40	20	0.6	Unshaded at site although river generally shaded by broad-leaved trees. Benthic algae and aquatic mosses.

4. Downstream of confluence with the Nant Mychudd (ST 032831)	12.0	54	7.8	5	39	16.1	8	0.50 0.30	36	9.0	Only bank-side water shaded by broad-leaved trees. Aquatic mosses present.
5. Downstream of confluence with the Afon Clun (ST 036818)	13.4	49	2.4	5	56	12.5	11	0.47 0.33	5	1.5	Unshaded although some broad-leaved trees on banks.
6. Upstream of Brynsadler (ST 030811)	14.3	46	2.4	5	63	12.0	12	0.40 0.30	16	2.9	Unshaded; some broad-leaved trees on banks. Aquatic mosses present.
7. Downstream of Miskin Sewage Works (ST 056796)	19.6	30	1.6	5	78	11.8	14	0.75 0.47	25	6.6	Unshaded; bushes and a few trees on banks. Prolific growth of <i>Cladophora</i> .
8. Upstream of Peterston Sewage Works (ST 082762)	27.0	20	1.6	5	113	13.5	14	0.56 0.31	21	8.3	Unshaded; bushes and herbs on banks. Prolific growth of <i>Cladophora</i> .
9. Downstream of St Fagans Sewage Works (ST 126772)	33.1	12	1.1	5	130	19.6	15	0.28 0.16	47	24.3	Unshaded; bushes and herbs on banks. Prolific growth of <i>Cladophora</i> .

TABLE 2. Water quality (January 1972–December 1973). Average and range are given for each determinand. The spatial relationship between the macro-invertebrate sampling sites and the chemical sampling stations is shown in Fig. 1.

Chemical station (grid reference)	BOD ₅ at 20°C (mg O ₂ l ⁻¹)	Dissolved oxygen (mg l ⁻¹)	Permanganate value					Suspended solids (mg l ⁻¹)	pH	Alkalinity (mg CaCO ₃ l ⁻¹)	Conductivity at 20°C (μS cm ⁻¹)	Temperature (°C)
			Ammonia (mg N l ⁻¹)	Nitrate (mg N l ⁻¹)	N/80 KMnO ₄ 4 h at 27°C (mg O ₂ l ⁻¹)	Nitrate (mg N l ⁻¹)						
C1: (ST 018859)	3.4 0.2–15.0	10.3 8.3–12.5	0.4 0.1–1.4	0.7 0.03–1.5	2.6 1.4–2.8	4.2 2.0–6.0	7.3 6.6–7.8	57 40–91	223 150–350	11.2 4.0–19.0		
C2: (ST 033827)	3.5 0.6–13.6	8.9 4.1–12.4	7.4 0.3–54.0	2.9 1.0–5.5	3.1 2.0–5.9	8.0 2.0–45.0	7.1 6.3–7.8	36 29–46	230 149–355	11.4 4.0–18.5		
C3: (ST 034815)	3.2 1.1–8.5	8.7 5.7–11.9	3.9 0.5–11.2	3.4 1.4–8.0	18.2 3.2–105.0	23.9 2.0–235.0	7.1 6.4–7.7	52 42–58	289 199–380	11.2 4.0–17.5		
C4: (ST 042811)	3.6 1.4–11.5	9.0 5.9–11.9	2.5 0.7–10.4	3.2 1.7–5.2	4.9 2.9–7.6	7.9 2.0–34.0	7.3 7.0–7.5	86 60–118	320 225–425	11.5 4.5–17.5		
C5: (ST 046806)	6.7 0.2–17.1	8.6 4.1–10.8	3.0 0.9–9.0	3.2 1.7–5.4	4.8 3.9–7.6	9.2 2.0–34.0	7.3 7.1–7.5	90 60–123	375 230–610	11.5 4.5–17.5		
C6: (ST 065781)	4.8 2.2–12.6	9.6 4.7–12.6	1.9 0.3–6.6	3.4 1.4–6.0	4.8 3.1–7.9	9.7 2.0–28.0	7.5 7.0–8.3	90 59–125	362 255–670	11.8 4.0–19.0		
C7: (ST 081761)	3.4 1.5–8.4	8.0 4.4–10.6	2.0 0.2–7.8	3.3 1.6–5.7	5.8 3.0–11.6	12.8 2.0–38.0	7.4 6.9–7.7	94 61–124	361 235–540	11.4 4.0–17.5		
C8: (ST 119769)	3.0 1.1–6.2	9.6 5.5–11.9	1.2 0.02–3.2	3.3 1.7–5.2	4.4 2.3–8.2	13.4 4.0–56.0	7.6 7.1–8.3	102 85–132	343 330–550	11.7 3.5–18.0		
No. of samples	18	18	18	18	8	18	18	7	18	18		

cient. This technique is considered generally satisfactory although conservative by Clifford & Stephenson (1975). It would appear sensible for groups to be joined at an average level of similarity rather than at the level of closest similarity between two species, one in each group, as occurs in nearest neighbour clustering and because of this Field & McFarlane (1968) recommended the use of average linkage clustering.

Wishart (1975) observed that Euclidean-Distance coefficients are biased towards those variables (species) which have large variances. Thus, those species with very variable abundances may assume exaggerated importance in the clustering process. In order to reduce this bias the data were standardized by subtracting the mean abundance of each species at a site from its abundance in the sample and dividing by the standard deviation. Such standardization should place more emphasis on distribution but it also means that species are being grouped more on the basis of their proportional occurrence than on their absolute abundance. Because of this, Squared Euclidean-Distance coefficients were also calculated using non-standardized data for comparison.

All the clustering methods used in the present study are available in the CLUSTAN 1C computer package (Wishart, 1975).

Results

A list of the species found during the survey and their average abundance at each site is provided in Appendix 1. An indication of the distribution of species within replicate samples is provided by giving (a) the number of samples in which the species occurred at a site and (b) the standard deviation of the mean based on these samples, i.e. zero counts not included (Appendix 1). Elliott (1977) concluded that it is best to express population density in the form of the arithmetic mean of the original counts along with confidence limits calculated using the factor derived from the logarithmic transformation. However, this approach was frustrated by the difficulty of finding a suitable model for transforming the Ely data. The commonly used $\log(x+1)$ was unsuitable.

The average abundance (zero counts included in their calculation) were used when calculating the coefficients of association. The species

clusters resulting from the different analyses are listed in Table 3. Clearly different procedures have led to the delimitation of different species clusters. Even where the same measure of association was used, e.g. Squared Euclidean-Distance, different clustering techniques produced different species clusters. Some methods proved very conservative. The Squared Euclidean-Distance coefficient when clustered by nearest neighbour produced few species groups (Table 3) irrespective of whether the data had been standardized or not. Ward's clustering of the Squared Euclidean-Distance coefficient produced fewer species groups when used with non-standardized data than when used with standardized data.

A basic assumption underlying the use of association analysis is that the grouping of species together implies that they may have similar environmental requirements (Greig-Smith, 1964). Knowledge of the ecology of at least the commoner macro-invertebrate species in the R. Ely might have established the extent to which this was true for the methods used in this study. Unfortunately, in practice, insufficient information was available to determine this with any certainty. However, some species were grouped together by all or most of the procedures used. Green (1979) stated that if several clustering procedures, based on different algorithms related to different definitions of a group, all produce the same clusters of samples, the conclusion that they are real groups of some kind is a robust one. These robust groups of species are shown in Table 3. If these robust groups could also be shown to have ecological validity, they might be used as a basis for comparing the appropriateness of the clustering techniques used.

Group 1

This group is composed of the ephemeropteran *Baetis rhodani* and the chironomids *Poly-pedilum (laetum group)*, *Cricotopus trifascia*, *Eukiefferiella claripennis* and possibly *E. calvescens*. This group was particularly dominant at S7 and S8 (Fig. 2). The former site was downstream of Miskin Sewage Works and had the highest maximum BOD₅, about 17 mg O₂ l⁻¹, of the sites investigated; this had declined to about 8 mg O₂ l⁻¹ at Site 8. However, the dissolved

TABLE 3. Species groups resulting from the various clustering methods used. A number (1), (2), etc., is given to each clearly identifiable cluster and a solid horizontal line indicates cluster boundaries. For convenience when constructing the Table some clusters have been artificially split: these are denoted by the letters A, B, etc., but are actually part of one cluster. Where a species is part of another cluster this is denoted by (*) followed by Cl and the number of the other cluster, e.g. (*) Cl 6 shows that the species is part of Cluster 6.

Species	Squared Euclidean-Distance					
	Product moment correlation: nearest neighbour	Kendall's tau:		Non-standardized data		Standardized data
		nearest neighbour	Kendall's average linkage	Nearest neighbour	Ward's method	
<i>Asellus aquaticus</i>	* (1)	* (1)	* (1)	— (1)	— (1)	— (1)
<i>Baetis rhodani</i>	*	*	*	—	—	—
<i>Eukiefferiella claripennis</i>	* (2)	*	*	—	—	—
<i>Polypedilum</i> sp. (<i>laetum</i> gp.)	*	—	*	*	*	*
<i>Cricotopus trifascia</i>	*	*	*	*	*	*
<i>Eukiefferiella calvescens</i>	*	*	*	*	*	*
<i>Prodiamesa olivacea</i>	*	(*) Cl 7	*	—	—	—
<i>Trocheta subviridis</i>	—	*	(*) Cl 3	*	(*) Cl 3	*
<i>Nais communis</i>	—	— (2A)	(*) Cl 3 (2A)	*	(*) Cl 3 (2A)	*
<i>Orthocladus rubicundus</i>	—	—	(*) Cl 3	*	*	*
<i>Paracyclops fimbriatus</i>	* (3A)	—	*	*	*	*
<i>Wiedemannia</i> sp.	*	—	*	*	*	*
<i>Paracyclops poppei</i>	*	*	*	*	*	*
<i>Pristina idrensis</i>	*	*	*	*	(*) (2A)	*
<i>Synorthocladus semivirens</i>	*	*	*	*	*	*
<i>Nais elinguis</i>	*	*	*	*	(*) (3)	(*) (3)
<i>(A. aquaticus)</i>						(1)
<i>B. rhodani</i>					— (1A) (*) Cl 6	
<i>E. claripennis</i>					—	
<i>Polypedilum (laetum gp.)</i>					*	
<i>C. trifascia</i>					*	
<i>E. calvescens</i>					—	
<i>P. fimbriatus</i>					*	
<i>Wiedemannia</i> sp.					*	
<i>P. poppei</i>					*	
<i>P. idrensis</i>					(*) (3)	
<i>S. semivirens</i>					*	
<i>N. elinguis</i>					(*) (4)	(3)

<i>Conchapelopia melanops</i>	*	—	(*) C14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

FIG. 2. Spatial distribution of Robust Groups 1-8 (see Table 3) in the R. Ely. Group 1 is shown including (stippled) and excluding *Asellus aquaticus*. Group 5 includes *Nais barbata*, *Paratrichocladius rufiventris* and *Cricotopus bicinctus*.

oxygen concentration remained relatively high, in excess of $4 \text{ mg O}_2 \text{ l}^{-1}$ at both sites because of the shallow turbulent nature of the river. Although phosphate concentrations were not determined at the time of the survey, later studies (Murphy, 1980) showed that orthophosphate concentrations could be as high as 2 mg P l^{-1} at Site 7 and 1.2 mg P l^{-1} at Site 8. These, together with high nitrate concentrations (Table 2), stimulated prolific growths of *Cladophora* at both sites.

Baetis rhodani is noted for its tolerance of pollution by rapidly biodegradable organic matter such as sewage; mild pollution of this nature promotes an increase in numbers (Hawkes, 1979). Ghetti & Bonazzi (1977) found

this species to dominate the macro-invertebrate fauna at Langhirano on the Torrente Parma, Italy, where the water quality was similar to that of the R. Ely. It was less dominant at sites where the water quality was better or poorer than this. Less is known about the other species. Lehmann (1972) refers to *E. claripennis* ($\equiv$ *E. hospita*) as living principally among mosses in swift running water. Hawkes & Davies (1971) and Szczesny (1974) have observed the increased dominance of this species in reaches of rivers recovering from sewage pollution. The former authors believed that oxygen concentration was the principal factor determining the distribution of *E. claripennis*, and also *B. rhodani*, in the river they studied. In particular, the summer inci-

dence of both species was progressively suppressed as the amount of organic pollution increased because of the greater severity of oxygen depletion during the summer months. *Eukiefferiella calvescens* is also particularly associated with the presence of mosses, but generally in unpolluted rivers (Learner *et al.*, 1971; Lehmann, 1972). However, Wasson (1977) found this species to dominate the macro-invertebrate fauna of an organically enriched region of the Isère where *Cladophora* was abundant at certain times. *Polypedilum* and *C. trifascia* were particularly prominent at eutrophic sites on the R. Ely where the river was recovering from sewage pollution. Similarly, Wasson (1977) found *P. laetum* and *C. trifascia* largely restricted to organically-enriched reaches of the Isère. Besch & Hofmann (1968) noted that *P. laetum* was particularly tolerant of organically polluted waters in the lower Steinach where it was associated with the bacterium *Sphaerotilus*. In the R. Ely *Polypedilum* (not necessarily *P. laetum* itself) was the only member of Group 1 which occurred at S2 downstream of the Coedely Coking Plant.

Product-moment correlation, unlike the other methods used, linked *B. rhodani* with the crustacean *Asellus aquaticus* as a separate group whereas the use of Kendall's *tau* coefficient resulted in *A. aquaticus* being grouped with all the Group 1 species (Table 3). This is probably because Kendall's *tau* is calculated from the ranked values of abundance at the sites, which are very similar in this instance, whereas product-moment correlation is sensitive to differences in absolute abundance which fluctuate more widely. Hawkes & Davies (1971) demonstrated the association between large numbers of *A. aquaticus* and eutrophic conditions as indicated by thick growths of *Cladophora*. Similarly in the R. Ely highest population densities occurred where there was an abundance of filamentous plants in the eutrophic lower reaches. Thus, the grouping of *A. aquaticus* with the Group 1 species would appear ecologically sound although unlike the other Group 1 species it was widely distributed, relatively abundant at S1 and absent from S3.

Group 2

This group consists of two copepod species, *Paracyclops fimbriatus* and the closely related *P. poppei*, empidiids of the genus *Wiedemannia*,

the naidid worm *Pristina idrensis* and the chironomid *Synorthocladius semivirens*. The group was particularly dominant at S1 where it formed 15% of the total macro-invertebrate population (Fig. 2). The water at this site was relatively clean although affected by the dumping of domestic refuse into one of the upstream tributaries. *Pristina idrensis* and the two *Paracyclops* species occur in sewage filter-beds (Curds & Hawkes, 1975). However, *P. idrensis* was restricted to sites unpolluted by organic matter in the R. Cynon (Learner *et al.*, 1971) and, although occurring at some organically polluted sites in the R. Ely, it was most abundant at the relatively unpolluted site S1. The *Paracyclops* species are benthic in habit and crawl on and within the substratum. Hynes (1974) noted *P. poppei* occurring in sub-surface gravels along with *Pristina plumaseta*. In the R. Ely *Wiedemannia* sp. was found particularly associated with mosses and did not seem greatly affected by organic pollution. Hughes (1975) found that *Wiedemannia bistigma* was most common at organically polluted sites on the R. Cynon. The association of *Wiedemannia* with the other Group 2 species may therefore be determined more by the distribution of aquatic mosses than by water quality. *Synorthocladius semivirens* appears to be typical of the potamon (Besch, Hofmann & Ellenberger, 1967; Lehmann, 1971; Brooker & Morris, 1980) but the population densities of this species are clearly enhanced in montane rivers where enrichment from sewage occurs. Szczesny (1974) recorded that this species was tolerant of gross inorganic pollution in the Krynica stream in Poland where turbulence maintained a relatively high dissolved oxygen content but it is generally most abundant under conditions of mild organic pollution (Szczesny, 1974; Kownacki, 1977), especially where fine-grained substrates occur. It appears that the presence of Group 2 species together is generally indicative of very mild organic enrichment.

Group 3

This group is less clearly defined than the previous two groups (Table 3). It is composed of the worm *Nais elinguis* and the chironomids *Conchapelopia melanops*, *Microcricotopus rectinervis* [$\equiv$ *Nanocladius rectinervis*—see Saether (1977)] and *Brillia longifurca*. *Nais elinguis* is

known to occur abundantly in shallow turbulent rivers with stony substrates which are organically polluted (Szczesny, 1974; Dumnicka & Pasternak, 1978; Learner, Lochhead & Hughes, 1978) especially where finer particles occur (Szczesny, 1974). This species is, however, much less tolerant of high BOD values, low oxygen concentrations and high ammonia concentrations, related to gross organic pollution, than *Tubifex tubifex*, *Limnodrilus hoffmeisteri* and *Lumbicillus rivalis* (Korn, 1963; Dumnicka & Pasternak, 1978) which also occur in the R. Ely. Much less is known about the response of *Conchapelopia melanops* to pollution. This species, living primarily on vegetation, is tolerant of a wide range of conditions, being of widespread occurrence in both upland and lowland streams and along lake shores (Lehmann, 1971; Lindegaard-Petersen, 1972). The larvae of the other two chironomids in Group 3 are also found predominantly on vegetation (Lehmann, 1971; Lindegaard-Petersen, 1972). *Brillia longifurca* was originally considered a lake species (Thienemann, 1944) but in recent years it has been associated frequently with sewage pollution of riverine habitats (Besch & Hofmann, 1968; Hawkes & Davies, 1971; Learner *et al.*, 1971; Szczesny, 1974) although it also occurs in unpolluted reaches (Lindegaard-Petersen, 1972). In the R. Ely it was only found at more heavily polluted sites, even occurring at S2 downstream of the Coedely Coking Plant. *Microcricotopus rectinervis* was first recorded in Britain quite recently (Pinder, 1974) but its occurrence in the R. Ely and in the R. Wye, particularly in the lower reaches (Brooker & Morris, 1980) indicate that it has been overlooked in the past. Lehmann (1971) found this species in the middle and lower course of the Fulda. In the Ely, although widely distributed, it was most abundant at organically polluted sites. Group 3 species were particularly abundant at S4 where they accounted for 15% of the total macroinvertebrate population. Above this site the main river was badly polluted by sewage- and coking-effluent and, despite substantial dilution by relatively clean water from the Nant Mychydd, water quality at S4 is poor (Table 2). In view of the tolerance of these species to some organic enrichment it is curious that this group was not more abundant at S7 and S8 downstream of Miskin Sewage Works where the water quality was similar to that at S4 (Table 2). A possible

explanation in view of the importance of vegetation for these species is that aquatic mosses were present at S4 but not at S7 and S8. The other two sites where Group 3 species were relatively important, S3 and S6, were also characterized by the presence of mosses. The greater proportion of fine substrate at S4 (Table 1) may also have been beneficial for *N. elinguis* (Szczesny, 1974). Group 3 species were intolerant of conditions at S2 downstream of the Coking Plant and at S5 which was particularly affected by high concentrations of coal particles and high permanganate values (Table 2). It is probable that phenols and other toxic substances were also present. In the Ely it would appear that Group 3 species together are indicative of mild to moderate organically polluted conditions provided suitable plants are available.

Group 4

This group consists of the snail *Ancylus fluviatilis*, the chironomid *Conchapelopia pallidula*, the naidid worm *Nais variabilis* and the beetle *Limnius volckmari*. These four were grouped together by the Squared-Euclidean Distance coefficient whatever clustering method was employed (Table 3) probably because this coefficient tended to cluster together species having similar absolute abundances or similar standardized values of abundance (standardized data). This group was much less clearly differentiated by the use of Kendall's *tau* or product-moment correlation. *Ancylus fluviatilis* is used in biotic indices of water quality such as the Chandler's score (Chandler, 1970) as an indicator of unpolluted or virtually unpolluted waters. However, Wasson (1977) found greatest numbers of this species associated with the filamentous bacterium *Sphaerotilus* in the Isère and, from its presence at most sites along the lower Ely, it appears relatively tolerant of sewage pollution provided the water is well aerated. Bryce *et al.* (1978) noted that *Ancylus* was absent from those reaches of the R. Lee system where the oxygen saturation value remained below 50% for considerable periods. *Limnius volckmari* is also generally considered to be intolerant of organic pollution but it did occur in reduced numbers in the middle and lower reaches of the Ely and is able to survive in places where turbulence keeps the water well aerated (Learner *et al.*, 1971). *Conchapelopia pallidula* inhabits a wide variety

of substrates (Dittmar, 1955). Learner *et al.* (1971) found it at all the sites they investigated on the R. Cynon including those polluted by sewage and coal particles. However, in the present study this species had a more restricted distribution (Appendix 1) particularly in the lower reaches of the Ely. *Nais variabilis* has frequently been found associated with sewage pollution in shallow turbulent streams and rivers (Learner *et al.*, 1971; Szczesny, 1974; Kownacki, 1977) although this species may be less tolerant than *Nais elinguis* and *N. barbata* (Korn, 1963), both of which also occur in the Ely.

Although all the Group 4 species are tolerant of some organic pollution, they were most important at the very mildly polluted sites (S1 and S3) where they accounted for 6% and 20% of total macro-invertebrate abundance respectively (Fig. 2).

Group 5

The anthomyiid *Limnophora*, the cyclopoid *Eucyclops agilis*, and the chironomids *Macropelopia nebulosa* and *Cricotopus tremulus* were grouped together by virtually all the clustering procedures used. However, their contribution to macro-invertebrate abundance was about 1% or less at all sites and the significance of their association is unclear. Product-moment and Kendall's τ coefficients of association indicate that the worm *Nais barbata*, and the chironomids *Paratrichocladius rufiventris* and *Cricotopus bicinctus* may also be part of Group 5. These three species were generally very abundant at all sites affected by organic pollution except S9 (Fig. 2). *Nais barbata* often occurs abundantly in the organically polluted reaches of rivers with stony substrates especially in association with *Cladophora* (Learner *et al.*, 1978). Both *P. rufiventris* and *C. bicinctus* similarly occur abundantly in such environments although the filamentous alga may not necessarily be *Cladophora* (Hawkes & Davies, 1971; Learner *et al.*, 1971; Wasson, 1977). *Cricotopus bicinctus* has also been found in large numbers associated with growths of *Sphaerotilus* (Wasson, 1977). These three species were together most abundant at S4 where they accounted for over 60% of total macro-invertebrate abundance. In this respect they show some similarity to Group 3 but unlike Group 3 they were also dominant at S5.

Group 6

This group consists of the snail *Lymnaea peregra*, the leech *Glossiphonia complanata*, the amphipod *Gammarus pulex* and the water mite *Hygrobatas fluviatilis*. The tolerance of *L. peregra* to sewage pollution is well known (Hawkes, 1979) probably because, being air-breathing, it is unaffected by low oxygen concentrations. Dussart (1979) observed that the abundance of this species tended to increase as the calcium, potassium and chloride (probably related to sewage pollution) content of the water increased. *Lymnaea peregra* was most abundant at S9 on the R. Ely where the alkalinity was the highest of any site sampled and the chloride concentration was relatively high. This site was one of the least polluted of the sites investigated (Table 3). *Glossiphonia complanata* occurred at most sites on the R. Ely but was found in greatest numbers at S9. Murphy (1980) in a more recent survey of the Ely noted that high summer densities of this species occurred where the river was unpolluted or mildly polluted with sewage. Bryce *et al.* (1978) refer to this species as occurring in unpolluted or mildly polluted waters in the R. Lee system, and Matysiak (1976, 1978) concluded that *G. complanata* is less tolerant of sewage than the often co-existing leech *Erpobdella octoculata*. This latter species was much more abundant in the R. Ely than *G. complanata* but was restricted to sites 7, 8 and 9 (Appendix 1) and could not be included in the species-association analysis. Greatest numbers of *E. octoculata* occurred at S7 and lowest at S9 which is the converse of the pattern of *G. complanata* abundance. The association between *G. complanata* and *L. peregra* probably indicates some similarity in environmental response but there may also be a biotic influence in that molluscs are the chief prey of *G. complanata* (Elliott & Mann, 1979). Young & Ironmonger (1980) have shown this species, when offered a wide variety of foods under laboratory conditions, to feed extensively on *L. peregra*. *Gammarus pulex* is adversely affected by sewage pollution because of its intolerance of low oxygen concentrations (Hawkes & Davies, 1971). However, this species may be fairly numerous in the well-aerated riffles of organically enriched reaches of turbulent rivers (Hawkes, 1979); this appears to be the situation in the lower Ely. The water mite *Hygrobatas fluviatilis* was widespread

in the R. Ely. The larvae are parasitic on chironomid midges (Jones, 1967) but the host spectrum is not known. Learner *et al.* (1971) also found this species to be widespread in the R. Cynon. However, highest populations in both rivers occurred at unpolluted or mildly polluted sites.

Group 6 species occurred in relatively low numbers but accounted for 7% of total macro-invertebrate abundance at S9 (Fig. 2). This was one of the least polluted sites but was probably not that dissimilar in water quality from S1 and S3 and yet this group was, for unknown reasons, much less abundant at these latter sites.

Groups 7 and 8

These groups (Table 3) are best dealt with together. The tubificid worm *Tubifex tubifex* and the enchytraeid worm *Lumbricillus rivalis* are associated together as a species pair by all the association methods used in the present study except Kendall's *tau* which groups the tubificid worm *Limnodrilus hoffmeisteri* along with them. This latter species was grouped with the ephemeroptera *Baetis scambus* by the other methods. *Lumbricillus rivalis* and *T. tubifex* often occur together in shallow turbulent rivers wherever pollution from sewage occurs (Learner *et al.*, 1971; Edwards *et al.*, 1972; Dumnicka, 1978; Dumnicka & Pasternak, 1978; Scullion & Edwards, 1980) although Dumnicka (1978) also noted the co-dominance of *L. rivalis* and the tubificid *Limnodrilus udekemianus* where the substrate was slimy sand rather than mud. The latter species was not found during our study although it does occur in low numbers in the R. Ely (Murphy, 1980). The *L. rivalis*-*T. tubifex* combination appears to be much less important in sewage polluted reaches of lowland rivers. It is probable that *L. rivalis* is less tolerant of muddy substrates than is *T. tubifex* because of differences in respiratory behaviour (Berg, Jonasson & Ockelmann, 1962). The respiratory rate of *L. rivalis* is dependent upon the environmental oxygen concentration whereas that of *T. tubifex* is not, except at very low oxygen concentrations. Dumnicka & Pasternak (1978) found that the abundance of *L. rivalis* decreased as the dissolved oxygen concentration decreased from 75 to 1.6% of the air-saturated value: *T. tubifex* abundance was not correlated with dissolved oxygen concentration. In the R. Ely these two species were an important component of the

fauna at Sites 5-9 all of which were organically polluted. However, these sites were also affected by the deposition of coal particles.

The amount of fine matter in the sediments increases from S5 to S9 (Table 1) and so also does the abundance of both species. Ladle (1971) found much larger populations of *T. tubifex* in fine sediments compared with coarser ones. It is likely that the *L. rivalis*-*T. tubifex* association (Group 8) indicates a common response to sewage pollution and also to an increased incorporation of fine inert material into the substratum. This group also dominates the macro-invertebrate fauna at S2 where it accounts for 76% of total abundance. This is undoubtedly partly a response to sewage pollution (a storm-water overflow constantly discharged raw sewage upstream of Site 2), coupled with a tolerance of particularly high ammonia concentrations (Table 2). *Limnodrilus hoffmeisteri* also occurred at S2 but although it often occurs with *T. tubifex* in organically enriched rivers (Aston, 1973) and lakes (Milbrink, 1980), the two species do not necessarily display the same pattern of quantitative response to environmental change (Brinkhurst & Kennedy, 1965; Learner *et al.*, 1971; Szczesny, 1974; Wisniewski, 1976; Dumnicka & Pasternak, 1978; Särkkä & Aho, 1980). Although published observations do not provide an explanation for the differences in the pattern of quantitative change between these two species in the R. Ely, they do indicate that there may be an ecological justification for grouping *T. tubifex* and *L. rivalis* separately from *L. hoffmeisteri*.

As stated earlier those species-association coefficients based on absolute, rather than relative, abundance data grouped *L. hoffmeisteri* with *Baetis scambus* (Group 7). The latter species was the dominant ephemeropteran in the organically polluted but well aerated reaches of the R. Cynon (Learner *et al.*, 1971) and Bryce *et al.* (1978) also noted a possible association between *B. scambus* and organic enrichment in the R. Lee. In the R. Ely, *B. scambus* was the dominant ephemeropteran at Sites 1, 8 and 9 which were relatively mildly polluted by sewage whereas *B. rhodani* dominated at the more grossly polluted sites. Little information is available in the literature concerning the environmental requirements of *B. scambus* because until recently (Macan, 1979) it was considered impossible to distinguish between *B. scambus* nymphs and those of *B.*

bioculatus unless the nymphs were reared or adults collected to determine which species was present. Scullion & Edwards (1980) have shown that the abundance of *B. scambus* is greatly reduced in the presence of coal particles. However, the concentrations in the river they studied were greatly in excess of those in the R. Ely and it is unlikely that the distribution of *B. scambus* in the R. Ely was influenced in this way. Group 7 species were a particularly important part of the fauna at S9, but their importance at S1 is almost entirely due to *B. scambus* and at S2 entirely due to *L. hoffmeisteri*; therefore, it is not clear whether the grouping together of these two species has ecological support.

Discussion and Conclusions

One objective of this study was to determine which methods produced ecologically meaningful species groups. In general there appears to be ecological support for most of the robust groups identified (Table 3). However, none of the methods we compared produced species groupings identical with the robust groupings. Nearest neighbour clustering of the Squared Euclidean-Distance coefficient lacked discrimination. This method produced some small groups that seem ecologically meaningful but the tendency was for species to be associated into one or two large groups for which there appears to be little ecological justification. Of the less conservative methods, Ward's clustering of the Squared Euclidean-Distance coefficient based on standardized data grouped species from Robust Groups 1, 5 and 6 together which does not appear ecologically realistic in view of their dominance distributions (Fig. 2) whereas most of the species groups produced by the product-moment and Kendall's *tau* methods appear reasonable on the basis of the present state of knowledge about the species concerned. However, several species included in groups generated by nearest neighbour clustering of the product-moment correlation coefficient and by average linkage clustering of the Kendall's *tau* rank coefficient were not included when nearest neighbour clustering of Kendall's *tau* coefficient was used. Of the methods we compared, Kendall's *tau* coefficient clustered by the average linkage technique appears most likely to provide ecologically meaningful species groups. Product-moment correlation is also useful and because it is based on absolute abundance data whereas Kendall's

method is based on relative abundance data, the use of the two together provides a reasonable method for determining robust groups.

This study supports experience gained elsewhere (Williams, 1971; Pinkham & Pearson, 1976; Clarke, 1977) that species groups detected by the use of similarity measures and clustering techniques are to an appreciable extent influenced by the particular methods used. It is not surprising therefore that the species groups determined as a result of the present study bear little relationship to the macro-invertebrate species groups determined for the R. Cynon (Edwards *et al.*, 1975; Hughes, 1975; Pollard, 1977), another river of the South Wales coalfield somewhat similar to the R. Ely. However, other aspects are also important apart from the statistical procedures adopted. Although the above authors used similar macro-invertebrate sampling techniques and the same mesh size as ourselves, data refer to different times of the year. Edwards *et al.* (1975) data refer to July–August, Hughes (1975) used the maximum abundance of each species attained during a year, Pollard's (1977) data refer to May and ours were obtained during August. Undoubtedly species associations based on quantitative data will be affected by seasonal changes in population abundance associated with the life-histories of the species involved and also with any seasonal changes in water quality (Hawkes & Davies, 1971; Frost, Chiu & Thomas, 1976; Clarke, 1977). Season will have less effect on the structure of the species groups based on presence-absence data but as mentioned earlier for the Ely data this approach may be too insensitive to be useful. Hamer & Soulsby (1980) also found quantitative differences to be more important than qualitative ones when differentiating between stream macro-invertebrate faunas in their study.

For many years river ecologists have attempted to distinguish macro-invertebrate communities characteristic of particular river types or particular river zones (Hawkes, 1975). We believe the statistical establishment of species groups is an important tool for this work, as well as for detecting the presence of pollution. However, Williams (1971) points out that many procedures exist for classifying data and the problem is not so much one of finding a method of analysis but of choosing the most appropriate one from the many that exist. We hope this study will aid selection of an appropriate method.

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Appendix

Distribution and average abundance (no. m⁻²) of macro-invertebrate species at the sites examined. Only those species which had an average abundance of at least 100 m⁻² at any one site or occurred at four or more sites are tabulated. The values below each mean indicate the number of samples in which the species occurred (in parentheses) and the standard deviation of the mean for these samples. The numbers in parentheses after the names of the rarer species indicate the sites at which the species was found.

Sites										
	1	2	3 (Tributary)	4	5	6	7	8	9	
No. of samples:	10	10	5	10	5	10	10	5	5	
Annellida (Oligochaeta)										
Naididae										
<i>Nais alpina</i> Sperb.	123 (6)	—	154 (3)	—	—	—	—	—	—	—
<i>N. barbata</i> (Müll.)	21 (2)	215	—	11700 (10)	40 (1)	540 (6)	535 (3)	2450 (4)	—	—
<i>N. communis</i> Pig.	308 (9)	134	38 (3)	510 (5)	—	40 (1)	1193 (3)	1693 (4)	4023	—
<i>N. elinguis</i> Müll.	26 (1)	190	52 (2)	901 (5)	—	92 (1)	—	117 (2)	1414	—
<i>N. variabilis</i> Pig.	55 (6)	—	86 (3)	1404 (8)	—	2291 (3)	429 (2)	0	—	—
<i>Pristina foreli</i> (Pig.)	145 (8)	94	22 (2)	373 (5)	—	869 (1)	—	—	—	—
<i>P. idrensis</i> Sperb.	260 (9)	110	24 (2)	64	—	—	—	—	—	—
<i>Stylaria lacustris</i> (Linn.)	—	253	—	57	80 (2)	0 (1)	—	—	—	—
				283 (9)	184 (5)	1829 (10)	760 (7)	44 (1)	—	—
Tubificidae										
<i>Limnodrilus hoffmeisteri</i> Clap.	436 (10)	588 (10)	42 (2)	932 (10)	810 (5)	453 (9)	784 (10)	1146 (4)	3428 (5)	2349
<i>Potamothrix moldaviensis</i> (Vejd. + Mr.)	—	—	—	—	—	—	—	—	326 (1)	—
<i>Tubifex tubifex</i> (Müll.)	107 (9)	1849 (10)	100 (4)	745 (10)	474 (5)	581 (9)	1294 (10)	1978 (5)	2072 (4)	1881
Enchytraeidae										
<i>Lumbricillus rivalis</i> Levin.	171 (10)	2563 (10)	20 (2)	844 (10)	1522 (5)	833 (10)	1318 (7)	1292 (5)	1790 (5)	1568
Lumbricidae										
<i>Eiseniella tetraedra</i> (Sav.)	3 (3)	—	10 (2)	5 (3)	—	1 (1)	3 (2)	—	—	—

		Site									
		1	2	3	4	5	6	7	8	9	
No. of samples:		10	10	5	10	5	10	10	5	5	
(Tributary)											
Annelida (Hirudinea)											
Glossiphoniidae											
<i>Glossiphonia</i>	5	—	—	2	2	—	2	1	16	64	
<i>complanata</i> (Linn.)	(5)	0	—	(1)	(2)	0	(2)	(1)	(3)	(5)	
Erbodellidae	—	—	—	—	—	—	—	—	—	83	
<i>Erbodella</i>	—	—	—	—	—	—	—	—	—	—	
<i>octoculata</i> (Linn.)	8	—	—	—	2	—	2	11	2	124	
<i>Trocheta subviridis</i> Dut.	(6)	8	—	—	(2)	0	(2)	(8)	5	(5)	
Arthropoda (Crustacea)											
Cyclopidae											
<i>Eucyclops agilis</i> (Koch, Sars)	2	—	—	—	200	—	45	—	50	—	
<i>Paracyclops</i>	140	—	—	—	(1)	—	(2)	35	(1)	—	
<i>fimbriatus</i> (Fisch.)	(4)	100	—	—	270	—	21	52	—	—	
<i>P. poppei</i> (Rehb.)	93	—	—	—	(3)	656	(2)	134	133	—	
	(5)	152	—	—	120	40	10	2	—	—	
					(2)	566	(1)	(1)	—	—	
Asellidae											
<i>Asellus aquaticus</i> (Linn.)	256	—	—	—	20	—	597	8615	3180	354	
	(10)	241	—	—	(2)	127	(10)	823	(5)	(4)	
Gammaridae											
<i>Gammarus pulex</i> (Linn.)	1	—	—	12	1	—	—	1	8	196	
	(10)	—	—	(2)	(1)	—	—	(1)	(3)	(5)	
Arthropoda (Insecta)											
Baetidae											
<i>Baetis rhodani</i> (Pict.)	21	—	—	108	419	156	189	1324	600	186	
	(1)	—	—	(3)	(10)	610	(8)	215	(5)	(4)	
<i>B. scambus</i> Etn	782	—	—	62	266	68	40	496	1064	2908	
	(10)	761	—	(3)	(7)	454	(6)	101	(9)	(5)	
Halipidae											
<i>Brychius elevatus</i> (Panz.)	—	—	—	—	2	—	—	—	586	146	
					(2)	0	—	—	(4)	(4)	
Elminthidae											
<i>Limnius volckmari</i> (Panz.)	22	—	—	226	11	2	1	—	4	—	
	(6)	32	—	(5)	140	(6)	(1)	—	(1)	—	

	Site									
	1	2	3 (Tributary)	4	5	6	7	8	9	
No. of samples:	10	10	5	10	5	10	10	5	5	
Mollusca										
Ancylidae										
<i>Ancylus fluviatilis</i> (Müll.)	131 (7)	121	90 (4)	74	—	85 (5)	2 (1)	102 (1)	2 (1)	—
Hydrobiidae										
<i>Potamopyrgus jenkinsi</i> (Smith)	704 (10)	1 (1)	20 (1)	—	—	—	—	—	2 (1)	—
Lymnaeidae										
<i>Lymnaea peregra</i> (Müll.)	—	—	—	7 (5)	6	39 (6)	98	10 (4)	578 (5)	896
Average abundance (including rarer species)	5821	5827	2410	34051	6380	8999	24205	26136	13534	
Total number of species (including rarer species)	64	16	44	57	28	41	40	39	38	

Rarer species found: *Hydra* ? *oligactis* (Pall.) (1, 7); *Dendrocoelum lacteum* (Müll.) (9); *Polycelis felina* (Daly.) (8); *Polycelis tenuis* (Iijima) (7); *Chaetogaster diaphanus* (Gruit.) (4); *Dero digitata* (Müll.) (4); *Nais pardalis* Fig. (3); *Ophidonais serpentina* (Müll.) (1); *Pristina aquiseta* Bourne (1, 3); *Aulodrilus plurisetia* (Fig.) (1, 9); *Pelocolex ferox* (Eisen) (3); *Tubifex ignotus* (Stolc) (4); *Lumbriculus variegatus* (Müll.) (3); *Syllodrilus heringianus* (Clap.) (3); *Cernosvitoviella* sp. (1, 3, 4); *Enchytraeus* ? *buchholzi* Vedj. (1, 2); *Fridericia* ? *bisetosa* (Levin.) (1); *Fridericia* ? *perrieri* (Vedj.) (1); *Henlea* sp. (3); *Helobdella stagnalis* (Linn.) (7, 8, 9); *Bryocampus zschokkei* (Schmeil) (1); *Macrocyclops albidus* (Jur.) (1); *Paracyclops affinis* (Sars) (6); *Leucira geniculata* (Steph.) (4); *Leucira moseleyi* Morton (1); *Ephemerella ignita* (Poda) (1, 3, 9); *Ecdyonurus dispar* (Curt.) (1); *Hydropsyche instabilis* (Curt.) (8, 9); *Hydrotilla tineoides* Dalm. (1); *Limnephilus* ? *lunatus* Curt. (4); *Melampophylax mucoreus* (Hag.) (8); *Plectrocnemia geniculata* McL. (1); *Polycentropus flavomaculatus* (Pict.) (1, 2); *Rhyacophila dorsalis* (Curt.) (1, 3); *Sericostoma personatum* (Spence) (1, 3, 4); *Oreodytes septentrionalis* (Gyll.) (4); *Potamonectes elegans* (Panz.) (9); *Dryops* sp. (4); *Elmis aenea* (Müll.) (1, 3, 9); *Oulimnius tuberculatus* (Müll.) (1); *Tipula* ? *lateralis* Mg. (4, 9); *Molophilus* sp. (5); *Pedicia* (*Triclyphona*) sp. (1); *Satchelliella* ? *trivialis* (Etn) (4); *Psychoda severini* Tonn. (4); *Culex* sp. (5); *Diamesa* sp. (1, 7, 8); *Cryptochironomus* sp. (1, 3); *Polypedium* sp. *cinctum* group (8, 9); *Brillia modesta* (Mg.) (1, 4, 6); *Metricnemus* sp. (5); *Orthocladus* sp. (3); *Palpomyia* sp. (1, 3, 9); *Stratiomyidae* sp. (1); *Chelifera* sp. (*flavella* type) (1, 4); *Chelifera* sp. (*trapezina* type) (1, 7); *Hemerodromia* sp. (4, 6); *Atractides spinipes* Koch (3); *Lebertia* sp. (9); *Sperchon glandulosus* Koen. (3); *Sphaerium corneum* (Linn.) (8, 9); *Pisidium* sp. (1).

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