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MULTIVARIATE ANALYSIS OF SALINITY EFFECTS ON MAYFLY DISTRIBUTIONS ALONG A COMPLEX RIVER CONTINUUM

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MULTIVARIATE ANALYSIS OF SALINITY EFFECTS ON

MAYFLY DISTRIBUTIONS ALONG A COMPLEX RIVER CONTINUUM

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DISSERTATION COMMITTEE

PREFACE

This study is written in the form required by the journal Ecology of the Ecological Society of America. The paper will be submitted to Ecology for publication.

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SALINITY STRESSES ALONG A COMPLEX RIVER CONTINUUM:

EFFECTS ON MAYFLY (EPHEMEROPTERA) DISTRIBUTIONS

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ABSTRACT

The association between the benthic community structure and the river gradient as described in the river continuum concept is evaluated in the saline stressed Washita River. Physical, chemical and biological variables were monitored at six sites in the river over 14 sampling periods during 1980 and 1981. Physical parameters represented stream discharge, sediment particle sizes, organic content of the sediment and related factors. Physical variables were measures of conductivity, pH and the major salts in the river (calcium, sulfate, sodium and chloride). Biological variables were subdivided into two groups of densities of mayfly genera from dredge samples and Dendy multiple-plate samplers, respectively. The Ephemeroptera represent one of the dominant groups of benthic insects in the river. The genera monitored provide a wide range of functional types (with respect to habitat selection, feeding preference and feeding modes).

Two-dimensional ordinations were produced for the physical, chemical, dredge and Dendy groups of variables using the ALSCAL model of three-way nonmetric multidimensional scaling. The ALSCAL model summarizes variation over the 14 sampling periods. Scales were produced which represent river gradient effects and local effects for physical and chemical variables. Rank correlations of the dimensions from all ordinations suggest that both river gradient and local effects influence the structure of the benthic community. River gradient dimensions for physical and chemical variables are highly correlated with a dredge and a Dendy dimension. The remaining dredge dimension is correlated with local saline effects. The other Dendy dimension remains uncorrelated and may represent factors affecting colonization of Dendy samplers.

Benthic community structure is influenced by physical gradients in the river continuum. But saline effects, although governed by geomorphological processes, do not conform to the "typical" river gradient. This localized saline impact influences the benthic community structure. Therefore, the river continuum concept must be modified if it is to be useful in the generation of ecological models in regions with high land and river salinity.

Key words: river continuum concept, benthos, community structure, salinity, stress ecology, ordination, Ephemeroptera.

INTRODUCTION

Because stream morphology creates linear patterns of variation in many ecologically important variables (Leopold et al., 1964), biological communities in many streams are thought to show distinct linear gradients in terms of species composition (Hawkes, 1975; Hynes, 1970; Pennak, 1971; Vannote et al., 1980). Vannote et al. (1980) proposed the "river continuum" concept as a means of predicting community development along linear stream gradients. This concept stresses the close interrelationships among physical factors such as flow rates, substrates and the habitat requirements of benthic invertebrates. The river continuum concept treats the stream community at a given site as a material processing unit which is controlled by the basinal morphology of the stream. Upstream sections are dominated by detrital input from terrestrial sources, while downstream sections are greatly influenced by autotrophic production of periphyton grazed by a predictable group of herbivorous insects. This concept relates directly to other recent, generalized theories for streams such as those pertaining to the spiraling of nutrients (Webster & Patten, 1979; Elwood et al., 1981). However, there are common situations where these "generalized" models may not apply. Minshall (1978) has pointed out that organic inputs from outside the stream may be of little importance to community organization in streams with high rates of internal, autotrophic production. These streams are often encountered in drier regions of in the western United States.

Previous studies have usually ignored or infrequently measured the impact of complex salinity gradients of streams in arid regions on the community structure of benthic invertebrates. These chemical parameters may well be more important for many algae (Blinn et al., 1981) and benthic consumers (Magdych, 1979b) than the variable flow rates, sources of detritus or substrates that change dramatically on a seasonal basis. The rapid decline of flow and prolonged evaporation in many western streams (as well as the highly variable inflow of groundwater of changing salinity concentrations) creates a mosaic along the stream channel in terms of chemical environments. These localized chemical gradients may isolate certain sections of the stream from other parts and create barriers to dispersal and effective stream "drift" of migrating species that require downstream mobility to obtain sufficient food or an adequate microhabitat (Corkum et al., 1977). I suggest that the material processing capabilities of these saline streams may be greatly modified from what is expected according to current models of more dilute streams.

Those north temperate streams where salinity concentrations have been most studied are located in watersheds with relatively high precipitation and high year-round flow regimes. In these streams there is often a slight increase in total salt concentrations along a river's continuum (Gore, 1980; Woods, 1965) and, thus, the influence of salinity apart from flow or other physical variables might not be evident. For example, Hynes (1970, p.45) noted that in the River Dee, Wales, there is a slight increase in salinity along the first 40 km of the stream's course. Salinity continues to increase but at a somewhat faster rate as the river flows through an industrialized valley (Fig. 1).

In contrast, rivers in the southwestern United States may have highly variable salt concentrations because of marked, seasonal variability in rainfall and runoff. The Washita River, in western Oklahoma, provides an excellent example. Here geological salt deposits differ greatly in chemical composition along the length of the river (Johnson et al., 1972). Furthermore, low flow conditions during extended periods of drought increase salt concentrations in portions of this river (Oklahoma State Dept. of Health, 1977). The localized geological distribution of salt deposits and the unpredictable seasonal fluctuations in rainfall create a complex mosaic of salt concentrations rather than a continuous gradient conforming to the river continuum. In the Washita River the major dissolved ions vary independently and in a non-linear manner along the river's downstream flow (Fig. 1). Seasonally, the relative inflows from dissolved salts in ground water (Carr & Bergman, 1976) and runoff from drainage basins with different salt deposits produce a spatial-temporal landscape that could create major barriers to species dispersal and affect community function. This study will determine if the benthic community structure conforms to physical, chemical or a combination of physical-chemical development along the river gradient.

If the benthic community is structured by physical processes, then we would expect rankings of sites within the river based on physical parameters (e.g., discharge, sediment size and organic content) to produce similar scales to ordinations based on biological parameters (e.g., benthic densities and functional feeding groups). The same relationship should apply if chemical processes are important. A lack of congruence between biological scaling and physical or chemical scaling would suggest either a combined effect by the latter two processes or no relationship to the selected variables.

STUDY AREA

Six sites over a 150 km reach of the Washita River in western Oklahoma were chosen to monitor biological, chemical and physical parameters from June 1980 to December 1981 (Fig. 2). These sites range from the river headwaters (which are intermittent during drought conditions) to a fourth order stream and provide a wide range of physical and chemical (Fig. 1) variation. Stream substrates consist of various combinations of sand and silt intermixed with twigs, branches and logs. The riparian vegetation shifts from a partially open to an open canopy along the study area. Dense algal growth produces oxygen supersaturation during some periods at all sites (Table 1). Autotrophic production is probably important at each site.

BENTHIC INSECT SAMPLING

Mayflies (Ephemeroptera) have proven to be useful organisms because of their sensitivity to environmental perturbations (e.g., Leonhard et al., 1980; Lewis, 1978; Rosenberg et al., 1980). For example, population densities of _Ephemerella doddsi_ decrease in response to very small increases in sulfate concentrations (Rader &

Winget, 1980). In the Washita River, mayfly populations were altered by changes in salt concentrations resulting from brine discharges from a demineralization plant (Magdych, 1979b).

The generic level of taxonomic identification indicates an ecological type in many aquatic insects (Wiggins & MacKay, 1978). Therefore, changes in the composition of insects in the stream community with respect to genera should indicate variation in the ability of the community to use different sources of organic matter and to alter resource availability to other communities downstream. Rankings of the sites based on densities of insect genera will reflect functional differences among the sites. The common mayfly genera in the Washita River are: *Baetis*, *Caenis*, *Choroterpes*, *Heptagenia*, *Hexagenia*, *Isonychia*, *Stenonema*, and *Tricorythodes*. *Baetis* and *Isonychia* inhabit substrates in open waters and are subject to direct changes in the chemical composition of the river. Furthermore, *Isonychia* is a filter feeder and may react to changes in suspended organic matter (Wallace & O'Hop, 1979). *Tricorythodes*, *Caenis*, *Choroterpes*, *Stenonema* and *Heptagenia* tend to be closely associated with the substrate and may be susceptible to changes in the mud-sand substrate of the Washita River such as particle size, oxygen depletion or formation of toxic hydrogen sulfide. *Hexagenia* build tubes in the substrate that combine elements of open water with chemical influences of the substrate. Thus, they will also serve as indicators of changes in the open water chemistry and sand substrates.

Populations of mayflies were monitored at each site with multiple-plate samplers (Hester & Dendy, 1962) and Ekman dredge samples. The multiple-plate samplers will be referred to as Dendy samplers in the remaining text. Four Dendy samplers were set at each site and allowed to colonize for at least four weeks prior to collection. Each sampler consisted of fourteen 7.5 x 7.5 x 0.3 cm hardboard plates with each pair of adjacent plates separated by two 2.5 x 2.5 x 0.3 cm hardboard spacers. The samplers were placed on the surface of the stream sediment in a section of uniform stream flow (pools were excluded). Due to losses of samplers between collections, an attempt was made to collect at least three samplers per site. These Dendy samplers provide a controlled substrate at each site which was exposed to the open water flow within the stream. This sampling design avoids complications from the effects of sediment-chemistry interactions on the mayflies. The hardboard material also simulates wood which is a common substrate associated with the mud-sand stream bottom.

To obtain independent data on distributions within the sediments, a series of 15 cm x 15 cm dredge samples were collected for comparison with Dendy samplers. Dredge samples were collected on intervals not less than 1.0 m along cross-sectional transects at each site in a section of uniform stream flow. These sections of uniform stream flow are comparable to riffle habitats with respect to flow conditions in many streams. True riffles are rare in the Washita River due to the scarcity of larger-sized substrates (gravel and cobble). Four replicate dredges were collected at each site from June 1980 to July 1981. Sample sizes were increased to 12 replicates per site from August 1981 to December 1981 to lower sampling variance. The number of transects taken at each site was a function of stream width and the number of replicates. The dredge samples were washed through a 30 mesh sieve and preserved in 10% formalin in the field. Final separation of organisms from the substrate was performed by elutriation (Magdych, 1981).

PHYSICAL ANALYSIS

Sediment samples were collected at the position of each dredge sample by removing a core 10 cm deep by 5 cm in diameter. These samples were stored frozen until analysis when they were thawed and dried at 100°C. A subsample was removed for measurement of organic content by loss of weight upon ignition at 500°C (Cox, 1976). The remaining sample of mineral particles was then passed through standard sieves of 5 mesh (4.0 mm), 10 mesh (2.0 mm), 18 mesh (1.0 mm), 35 mesh (0.5 mm), 60 mesh (0.25 mm), 120 mesh (0.125 mm) and 230 mesh (0.0625 mm) to determine percentages of particle size distributions (Carver, 1971; Hynes, 1970). Particles larger than 5 mesh (4.0 mm) were combined as a group and particles less than 230 mesh (0.0625 mm) were also combined in a silt-clay fraction. Stream velocity was measured at each dredge position at 6 cm from the surface and 6 cm from the bottom with a Teledyne-Gurley digital flow meter (model 645). Stream discharge was calculated from these data. These parameters summarize the major physical variation along the stream gradient.

CHEMICAL ANALYSIS

The most abundant salts in the Washita River are from gypsum (calcium sulfate) and salt (sodium chloride) deposits. Chlorides, sodium and calcium were measured in the laboratory with an Orion specific ion meter (model 407). Sulfates were assessed using Hach chemicals and a Bausch & Lomb Spec 70 spectrophotometer as described by Lind (1974). A Yellow Springs Instruments meter (model 33) was used in the field to determine conductivity and temperature. The pH was measured with an Extech meter (model 651) and turbidity with a Hach DR-EL meter. Dissolved oxygen was measured by Winkler titration (Lind, 1974).

DATA ANALYSIS

Ordination techniques have proven useful for describing various aspects of benthic communities (Culp & Davies, 1980; Gore, 1980; Rabeni & Gibbs, 1980) and can be very helpful for describing patterns of resemblance in community structure (Green, 1980). Gore (1980) used polar ordination to relate benthic communities in different seasons to physical-chemical parameters. I chose a similar format for the analysis of data in this study, but utilized an ordination technique which can summarize composite variation over the 14 sampling periods. Data were divided into three major groups of physical, chemical and biological variables as previously mentioned (Fig. 3). The biological variables were further divided for comparison of infauna and epifauna into two groups; dredge densities and Dendy sampler densities. This subdivision resulted in four groups of variables for data analysis.

Each group of variables was treated identically in steps 2 through 7 in the data analysis. Each group has 14 matrices representing sampling dates between June 1980 and December 1981 and each matrix consists of values for each measured variable at six sites. No data are available for Dendy densities in June 1980 so this group has 13 sampling dates. The values for each variable were standardized to a mean of zero and variance of one across sites for each sampling date. Standardization is commonly suggested for ordination techniques (Austin & Noy-Meir, 1971; Gauch et al., 1977). It reduces some problems involved in the comparison of variables which are measured on different scales as in this study. A matrix of average taxonomic distances (Sneath & Sokal, 1973) among the six sites was then calculated for each sampling date. The formula for average taxonomic distance is:

$$\sqrt{\left[\sum_{i=1}^{n} \left(X_{ij} - X_{ik} \right)^2 / n \right]}$$

n = the number of variables.

i = the variable being compared.

j & k = the sites compared.

x = the value of the variable.

The standardization and calculation of distances was performed using NT-SYS (Rohlf et al., 1979).

The average distance matrices for each group of variables was analyzed by the ALSCAL (Alternating Least-squares Scaling) model of three-way nonmetric multidimensional scaling (Takane et al., 1976; Kruskal & Wish, 1978). A program implementing this technique is available in SAS (Young & Lewyckyj, 1979). The ALSCAL model produces an ordination of the six sites for a group of variables which is a composite accounting for the variation among the 14 distance matrices (representing sampling dates). This composite ordination is called the "group stimulus space". Two-dimensional solutions were chosen for the ALSCAL analysis of each of the four groups of variables (Fig. 4). This solution was based on the number of sites being scaled, interpretability of the solution and lack of large reduction in "stress" with solutions of higher dimensions.

Stress measures the disparity between the rankings and the original distance measures. Low values of stress indicate high retention of information from the original data (Fasham, 1977; Kruskal & Wish, 1978). Values of average stress for the group stimulus space are presented in Figure 4. These values are based on the stress for each individual time space. Stress values fluctuate over time in each group of variables. For instance, the range of stress values for individual time spaces for physical variables is 0.076 to 0.283. The fluctuation in stress is partially due to the highly variable nature of the Washita River over time with respect to physical, chemical and biological parameters. Minimization of stress is not the sole factor for determining dimensionality. The interpretability of an n-dimensional solution is very important and must also be considered (Kruskal, 1964). In this study, a two-dimensional ordination provided a balance between considerations of interpretability and minimization of stress.

ALSCAL also produces a "time weight" for each sampling date (distance matrix). The time weight is a point in the time space which has the same dimensionality as the group stimulus space (Fig. 5). Individual spaces are calculated by multiplying the coordinates of the sites in the group stimulus space by the square root of the coordinates of the time weights. Individual time spaces represent ordinations of the sites for each sampling period. The sites will be farther apart along a dimension in the individual time space as the values of the respective time weight increases along that dimension. Therefore, the time weights may be useful for indicating critical time periods (ecological "bottlenecks") in the sense of Wiens (1977) because a high time weight for a sampling period indicates great separation of sites based on the group of variables being analyzed.

The group stimulus space, time weights and individual time spaces can be used to interpret the analysis of each group of variables. The explanation of the individual time spaces can be enhanced by the multiple regression of the variables for a specific sampling period on the dimensions of the respective individual time space. Regressions were performed for physical and chemical groups. The regression weights were then normalized to represent direction cosines or correlations of the variables with the dimensions (Kruskal & Wish, 1978).

The results of the regression analyses were used to help explain the two dimensions in both the physical and chemical ordinations (Fig. 3, step 8). Regressions were not performed for the dredge and Dendy ordinations. The variables in the latter two ordinations are densities of genera which are not continuous over time. This discontinuity results in the association of genera with dimensions in the individual time space changing over sampling dates. Because of this relationship it would be confusing to utilize regression analysis for the dredge and Dendy groups in the same manner as for the physical and chemical groups.

The distance matrices for each sampling time for the dredge and Dendy groups represent functional differences among the sites. The matrices of average taxonomic distances among sites for a sampling date are based on the available genera which represent ecologically functional types (Wiggins & MacKay, 1978). Therefore, these distance matrices are associated with changes in functional biological processes among sites such as material processing within the river. Each dimension of the ordination represents a scale of the change in benthic community function.

I compared the changes in benthic community function with changes in physical parameters (described by the river continuum concept) and chemical parameters using Kendall rank correlations of the dimensions among the respective group stimulus spaces and individual time spaces for the four groups of variables. The correlations among the dimensions of the individual time spaces are very similar to the correlations among the dimensions of group stimulus space, so only the latter correlations are presented here (Table 3). From this analysis, it is possible to interpret the dredge and Dendy scales and draw conclusions on the relative impact of the physical and chemical variables on the benthic community structure in the river (Fig. 3, steps 10 & 11).

RESULTS OF THE PHYSICAL ANALYSIS

The ALSCAL ordination of physical variables can be interpreted in terms of local and river gradient effects. Rankings of the sites along the first physical dimension do not correspond to the position of sites along the actual river gradient (Fig. 4) as would be expected from the literature on the stream continuum concept. I consider this disparity to be due to local differences in the geomorphology of the watershed. Dimension 1 has positive correlations for medium to coarse sands (as retained by 35 and 60 mesh sieves). This dimension is negatively related to organic content of the sediments and turbidity (Table 2). Sediments in site 1 are composed largely of coarse to medium sand. Sites 4, 5 and 6 are very similar with respect to these factors (Fig. 6). Sites 2 and 3 are composed of finer sediments in a zone of deposition with high organic content and increasing turbidity during spates (Fig. 6 & 7).

The second dimension of the physical ordination produces rankings of the sites which reproduce the position of sites on the river gradient with one exception (Fig.3). Sites 1 and 2 are reversed due to the effects of Foss Reservoir which is located between the two locations. This reversal represents a "reset mechanism" in the river continuum as discussed by Vannote et al. (1980). Variables associated with dimension 2 represent parameters which are controlled by the river continuum. This dimension is positively correlated with stream velocity, discharge and fine sands (as retained by 120 and 230 mesh sieves). It is negatively correlated with organic content and turbidity (Table 2 and Fig. 6 & 7).

The time weights summarize the variation of the physical structure of the stream over time (Fig. 5). An inverse relationship exists between the two dimensions in the time space. This pattern demonstrates seasonal changes and effects of the 1980 drought.

Rainfall and runoff are greatest in the late fall to spring. These are periods of high discharge which produce the greatest separation of sites along the river gradient (dimension 2). During low discharge periods in the rest of the year, the separation of the sites is along dimension 1 and is due to local aspects of the geomorphology. A drought in 1980 had its largest impact on the river discharge in September, October and November of that year. Time weights for these months have the highest values on dimension 1 in the time space. River discharge patterns were very different in 1981 and the time weights for these months are more closely associated with river gradient effects. These months in 1980 represent potential bottleneck periods with respect to physical parameters (Wiens, 1967).

RESULTS OF THE CHEMICAL ANALYSIS

The chemical ordination produces a river gradient axis and an axis of local effects as in the physical scaling. Chemical dimension 1 produces rankings of the sites which are identical to physical dimension 2. In this case, Foss Reservoir provides a chemical reset mechanism between sites 1 and 2. Dimension 1 is positively correlated with chlorides and sodium during 1980 and with chlorides and calcium in 1981 (Table 3). The switching of sodium and calcium is probably related to differences from leachate in the runoff from the watershed and management of releases of water from Foss Reservoir and brine from the demineralization plant during the 1980 drought and 1981 (Fig. 8).

Dimension 2 reflects variation of saline parameters at the local level. Rankings of sites along this dimension do not correspond with the river gradient. Dimension 2 is negatively associated with sulfate until June 1981. After that time, the pattern reverses to positive association with sulfates (Table 3). This relationship also appears to be associated with differences between 1981 and 1980 (Fig. 8). Irrigation of the surrounding agricultural land was heavy during late summer and fall of 1980 (personal observation). High use of irrigation often increases the leaching of salts from the soil (Hillman, 1981). Patterns of high rainfall in this region were very localized in 1981. This relationship would undoubtedly cause the pattern of saline leaching to be different from that due to irrigation.

The distances between sites based on chemical variables do not change in the same manner over time as in the physical ordination. This difference is demonstrated by comparing the positions of the time weights in the time space for chemical and physical variables (Fig. 5). Therefore, it should be possible to separate the effects of the chemical and physical parameters on the benthic community.

RESULTS OF THE BIOLOGICAL ANALYSIS

The dimensions from the dredge and Dendy ordinations were interpreted from the rank correlations with the dimensions from the physical and chemical ordinations (Table 4). Dredge dimension 1 is negatively correlated with chemical dimension 2, which represents local variation of salts in the river. Dredge dimension 1 is not correlated with physical dimension 1 (local physical effects). Dredge dimension 1 represents a scale of the benthic community which is associated with changes in the saline content of the river that arenot related to the river gradient or to local physical effects such as substrate variation. Dredge dimension 2 is negatively correlated with chemical dimension 1 and physical dimension 2. This dredge dimension represents variation in the benthic community which conforms to the river gradient. The benthic structure is associated with both saline effects and the river gradient.

Tricorythodes reaches high, more sustained infaunal densities at site 4 and to a lesser degree at site 3 (Fig. 10). Densities of *Choroterpes* have trends similar to *Tricorythodes*. Infaunal densities of *Baetis* and *Hexagenia* form distributional patterns which appear associated with the river gradient.

The projections of the dredge time weights in the time space do not present distinct patterns of association between the two dimensions of the time space. The distances among sites in the individual time spaces are a function of both the positions of sites along the river gradient and local saline effects. This complex relationship should not produce any cyclic, seasonal or interdimensional patterns as observed in Fig. 5.

Dimension 1 of the Dendy ordinations is positively correlated with dredge dimension 2 and negatively correlated with chemical dimension 1 and physical dimension 2 (Table 4). Therefore, the first Dendy dimension represents a biological scale related to the river continuum. The second Dendy dimension does not correlate with any of the other axes perhaps because the Dendy sampler provides a uniform substrate for epifauna at each of the sites. Factors affecting the colonization of these samplers may not be directly related to any of the measured parameters.

The projection of the Dendy time weights (Fig. 5) produces two clusters of points. One cluster is composed of sampling periods in 1980 which have high values on Dendy dimension 2. The second cluster primarily consists of sampling periods in 1981. These groupings represent differences between the two years which may have affected the colonization of Dendy samplers (Fig. 9).

DISCUSSION

Cushing et al. (1980) pointed out the difficulty of comparing physical, chemical and biological parameters. I addressed this problem with the ALSCAL model of multidimensional scaling. Ordinations produced by ALSCAL summarize relationships among sites over sampling time. Comparisons of the resultant ordinations for chemical, physical and biological variables demonstrate congruences among respective local and river gradient effects. The river gradient effects conform to the river continuum concept and suggest a causal relationship between the physical continuum and the mayfly community. However, the local effects also have an impact on the structure of the benthic community. Saline variables (such as sulfates) are closely associated with the structure of the mayfly community in the Washita River.

Tricorythodes is a collector-gatherer (Merritt & Cummins, 1978) and has a broad preference for substrates and flow regimes (Magdych, 1979a). This insect might be expected to reach higher densities in more productive reaches of the stream such as sites 5 and 6 (Table 1). Scrapers, such as Choroterpes, are expected to reach maximum densities in zones of high autotrophic production from periphyton

(Cummins, 1979). High densities of *Choroterpes* would also be expected at sites 5 and 6. However, both genera reach maximum densities at site 4. These unexpected infaunal distributions appear to be related to localized chemical patterns along the river gradient.

Further investigation of the response of the benthic community to saline effects is required. Fluctuations of environmental variables from year to year is great in regions similar to western Oklahoma. Complex interactions of these variables will undoubtedly have delayed effects on the benthic community structure, some of which will persist for several years. These effects can be best examined by long-term field studies of the benthic community. Emphasis on determining the relationship of these saline effects to the processing of organic matter by the benthic community would be very helpful in the development of management strategies for this and similar systems.

The increasing salinization of soils and streams in arid regions is a global problem. The effects of saline parameters must be considered when developing management strategies. Management models which consider only instream parameters such as flow regulation (Gore & Judy, 1981; Orth & Maughan, 1981) will not adequately describe saline river systems. In Oklahoma, the transition from a mesic region with water of low mineral content to an arid region with saline water occurs over a relatively short geographic distance. The eastern half of the state is mesic while the western half experiences problems of high stream salinity. Different river management strategies and water quality standards are necessary for each river basin of the state.

CONCLUSIONS

The saline effects described in this study are not predicted by the existing river continuum concept. These saline effects are orthogonal i.e., not correlated with actual downstream distance in the watershed and represent an additional, abstract gradient. Gradients of this type are probably very common in other regions although they may be due to different factors, such as acid rain (Singer, 1981). The pH of streams in areas with acidic precipitation is a function of the buffering capacity of the watershed. The buffering capacity may change along the river gradient and result in a gradient of pH which is orthogonal to the river gradient. Factors such as these are controlled by complex, non-linear geomorphological processes and yet embrace the general river continuum concept that stream community structure is a function of abiotic factors. Further research is neccessary in river systems of this type to identify these additional gradients and to measure the resiliency of benthic communities to these impacts along the stream continuum.

The river continuum concept was originally described in terms of instream factors (Vannote et al., 1980). My study demonstrates that other parameters do not conform to the river continuum but are closely associated with aspects of community structure. These additional parameters are distinct from reset mechanisms in the river continuum (Vannote et al., 1980) because they are uncorrelated with the river's downstream gradient. The river continuum concept can be expanded to incorporate these additional parameters (e.g., river salinity) by considering models of multiple gradients.

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Figure 1. Concentrations of certain salts in the River Dee, Wales and the Washita River, Oklahoma.

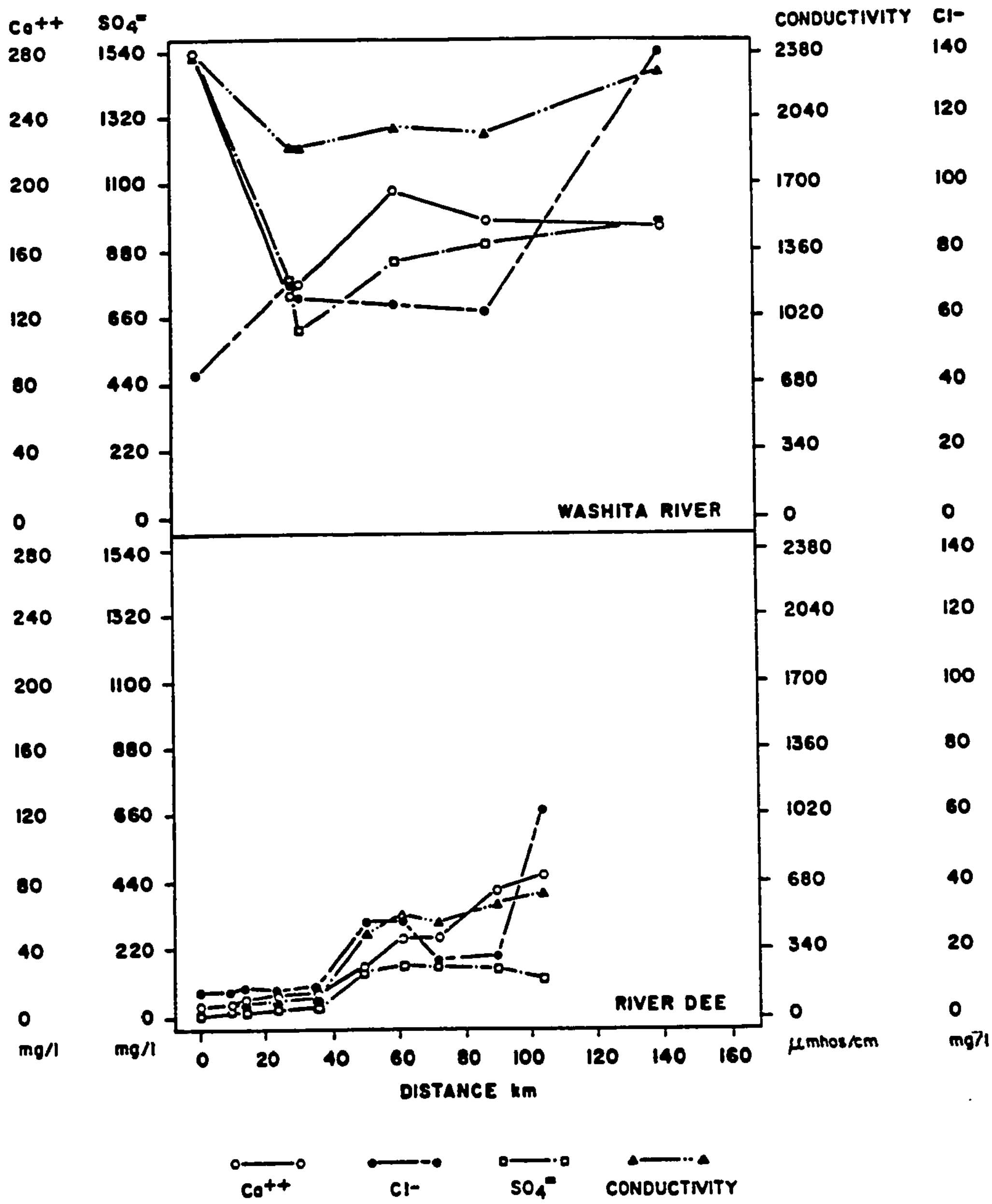

Ca++
SO4=
CONDUCTIVITY
Cl-
280
240
200
160
120
80
40
0
1540
1320
1100
880
660
440
220
0
2380
2040
1700
1360
1020
680
340
0
140
120
100
80
60
40
20
0
WASHITA RIVER
RIVER DEE
mg/l
mg/l
µmhos/cm
mg/l
0
20
40
60
80
100
120
140
160
DISTANCE km
Ca++
Cl-
SO4=
CONDUCTIVITY

Figure 2. Map showing the locations of the study sites.

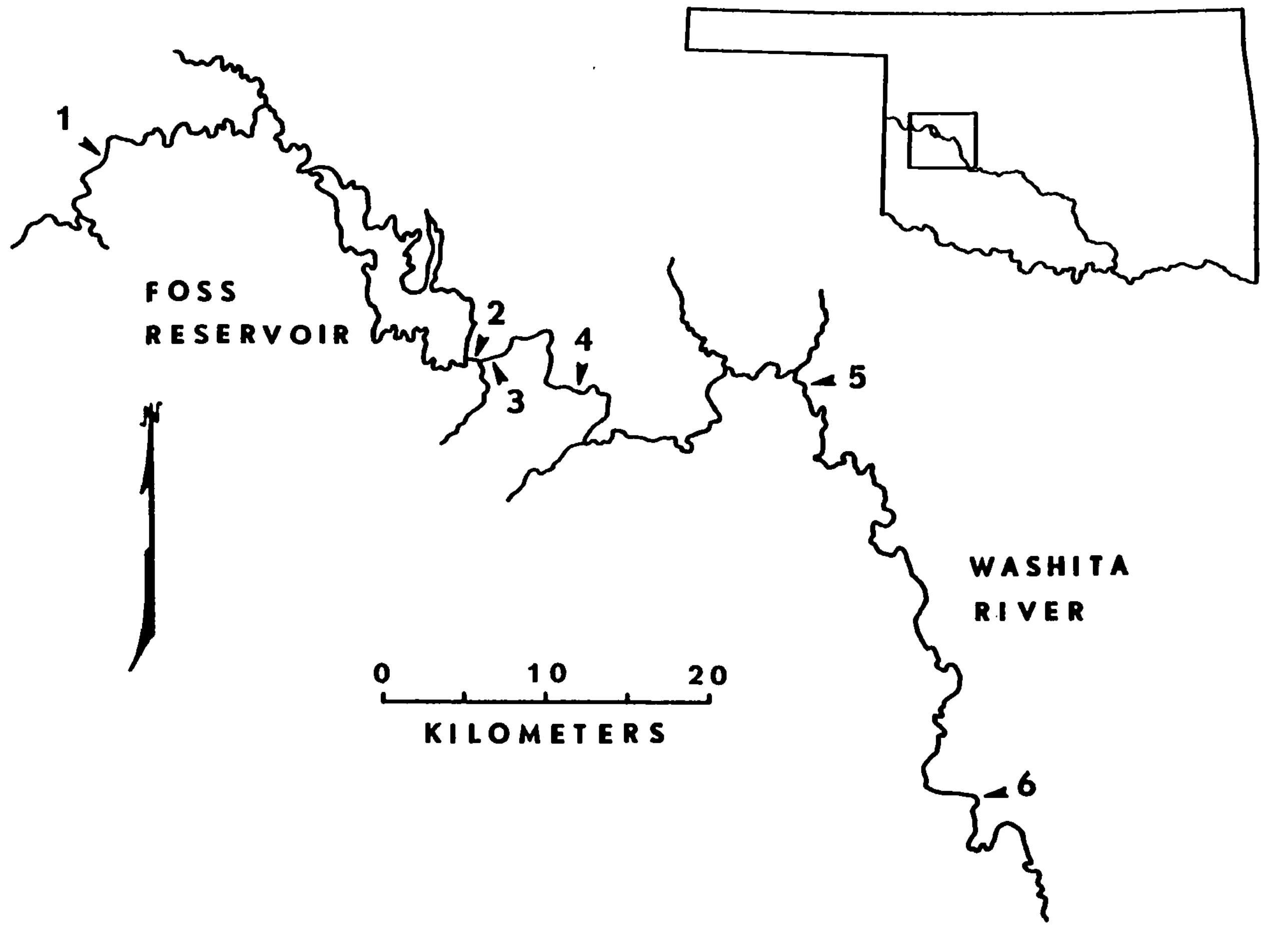
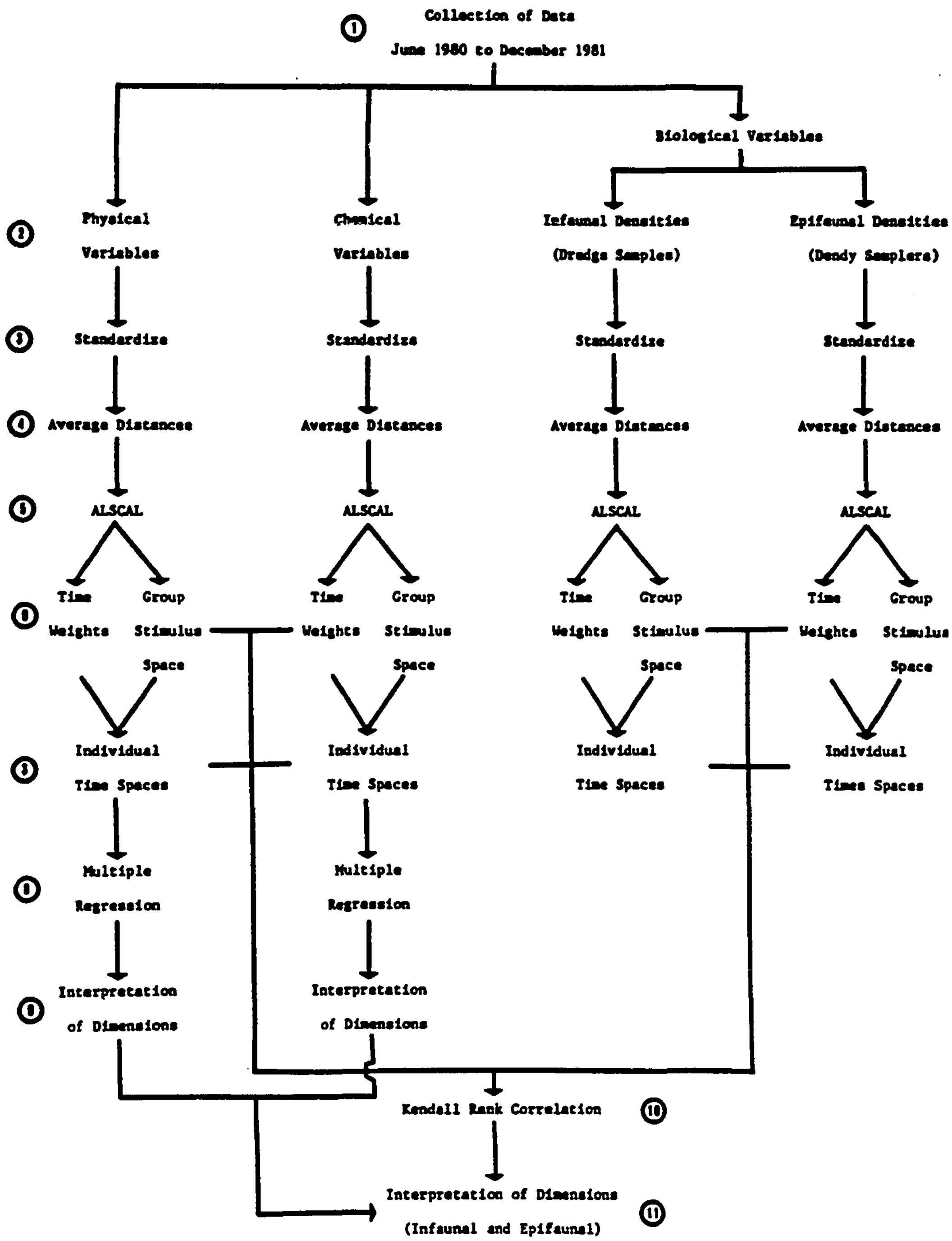

1
FOSS
RESERVOIR
2
3
4
5
6
WASHITA
RIVER
N
0
10
20
KILOMETERS

Figure 3. Flow chart of techniques used in data analysis. A detailed discussion of the techniques of analysis is given in the text.



1
Collection of Data
June 1980 to December 1981
Biological Variables
2
Physical Variables
Chemical Variables
Infaunal Densities (Dredge Samples)
Epifaunal Densities (Dendy Samplers)
3
Standardize
4
Average Distances
5
ALSCAL
6
Time Weights
Group Stimulus Space
7
Individual Time Spaces
Individual Times Spaces
8
Multiple Regression
9
Interpretation of Dimensions
Kendall Rank Correlation
10
Interpretation of Dimensions (Infaunal and Epifaunal)
11

Figure 4. Plots of the composite scales (group stimulus space) for the physical, chemical, dredge and Dendy sampler ordinations. The dimensions are scaled in relative units.

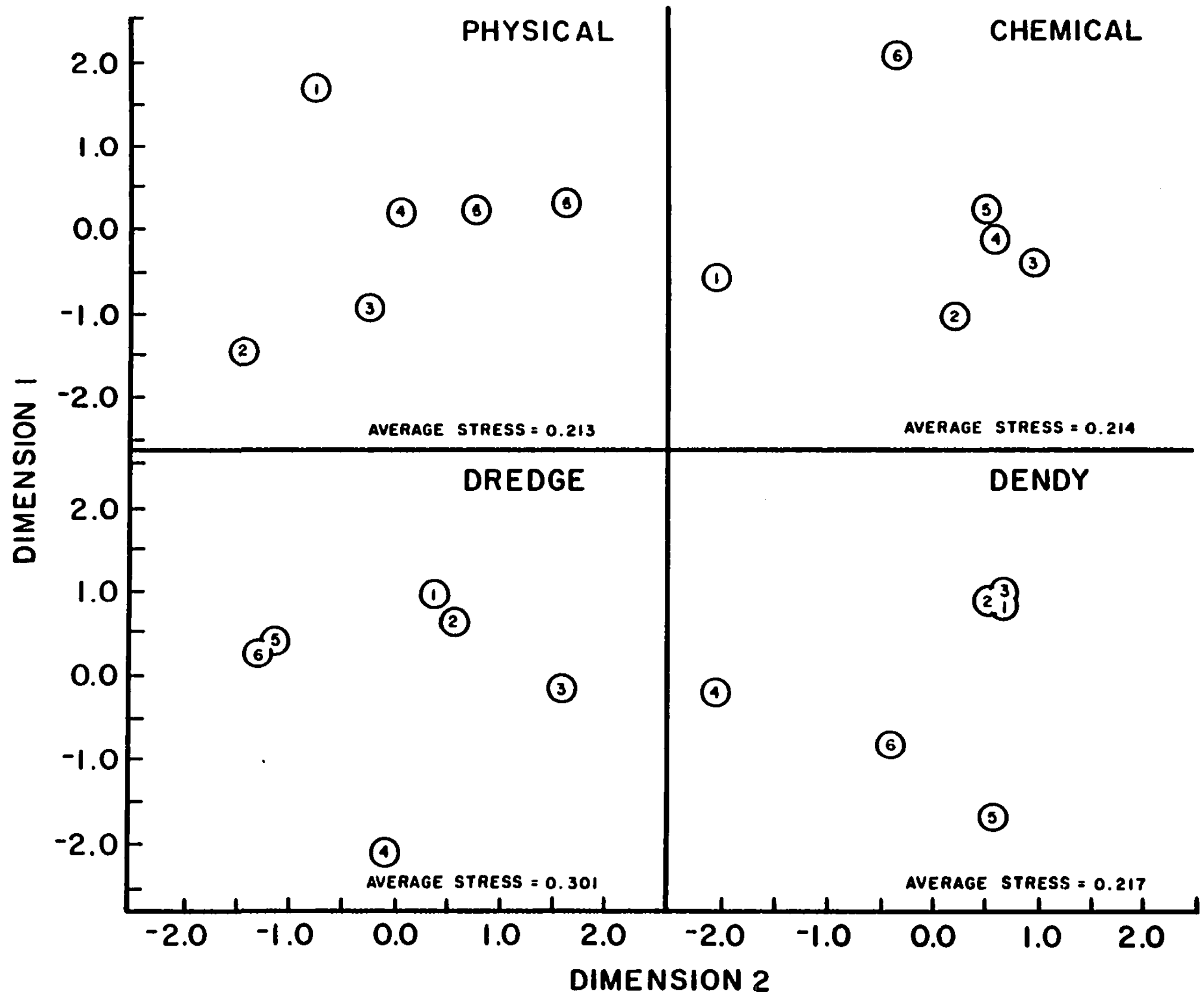

PHYSICAL
CHEMICAL
DREDGE
DENDY
AVERAGE STRESS = 0.213
AVERAGE STRESS = 0.214
AVERAGE STRESS = 0.301
AVERAGE STRESS = 0.217
DIMENSION 1
DIMENSION 2
2.0
1.0
0.0
-1.0
-2.0

Figure 5. Graphs of the time weights for each dimension for the ALSCAL ordinations of sites for physical, saline, dredge and Dendy parameters. Projections of sites for a specific time are obtained by multiplying the coordinate values of each dimension by the square root of the respective time weight. The dimensions are scaled in relative units.

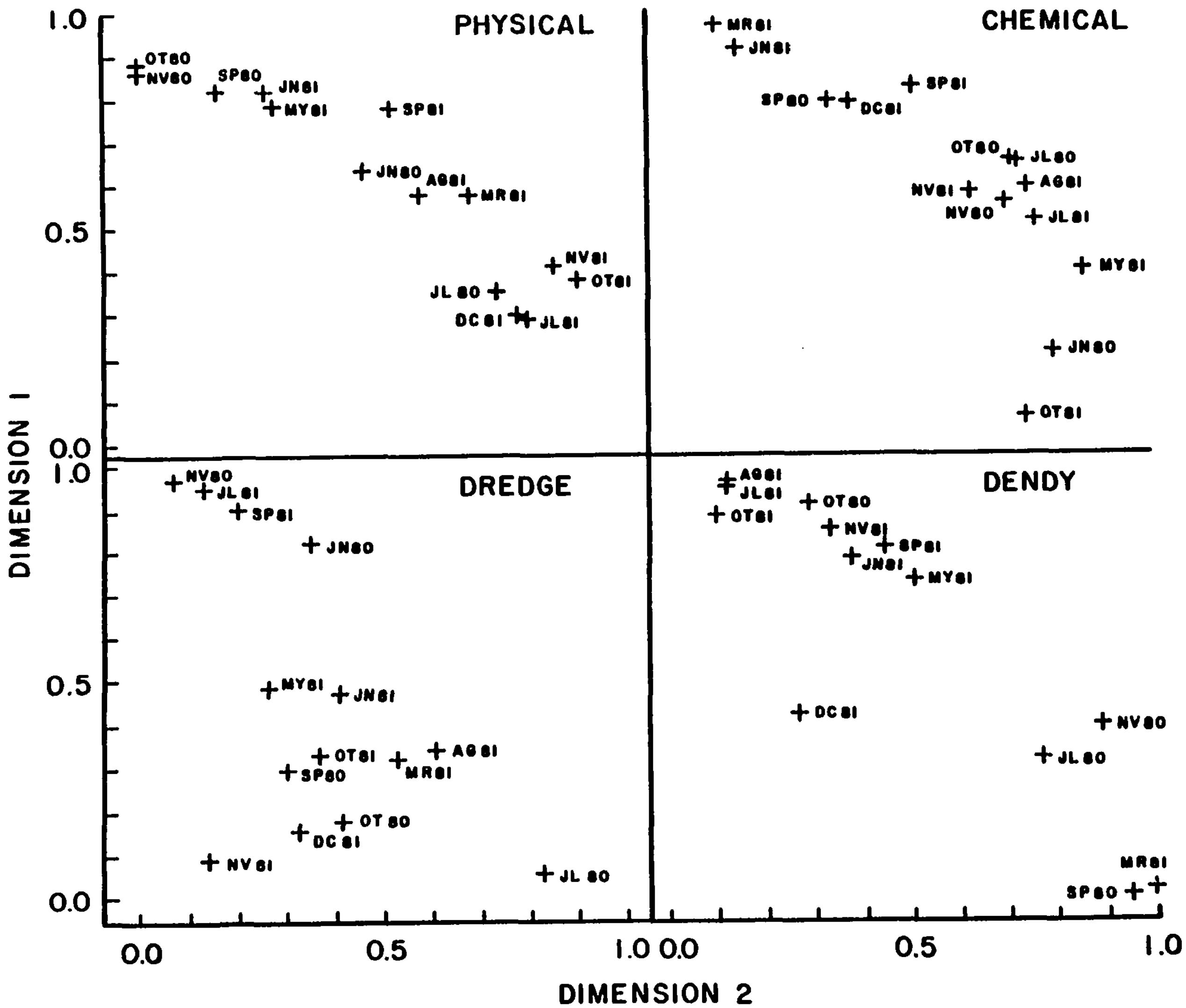
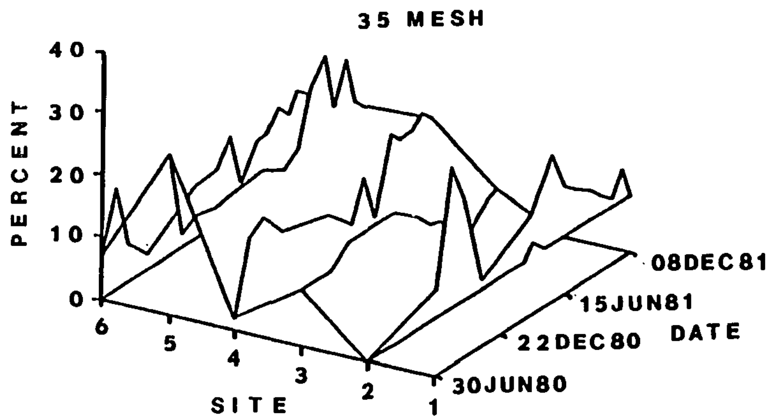
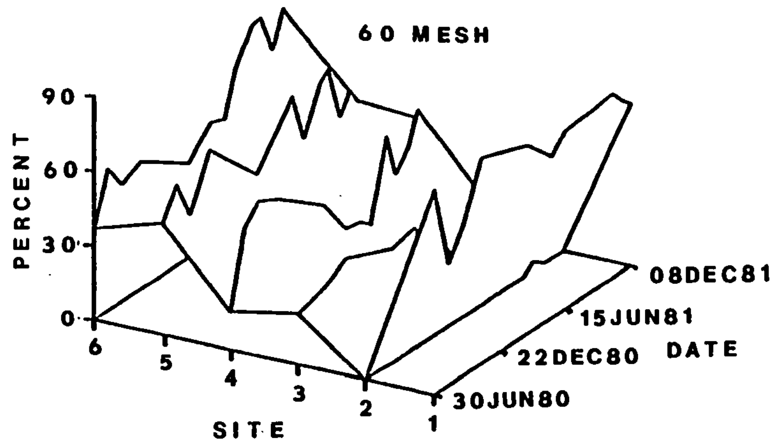
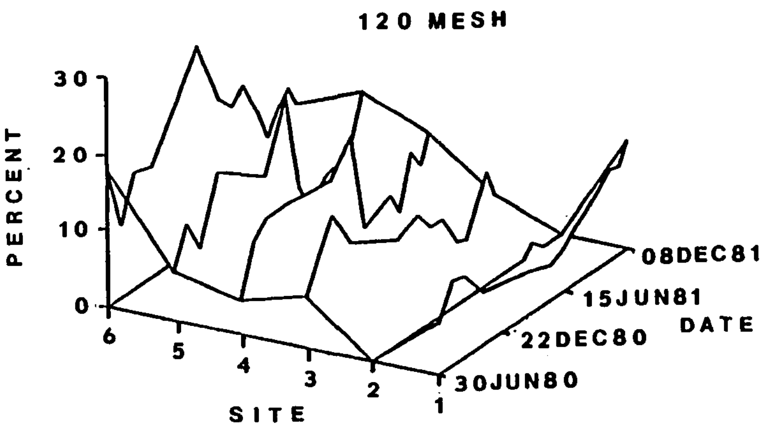

PHYSICAL
CHEMICAL
DREDGE
DENDY
DIMENSION 1
DIMENSION 2
1.0
0.5
0.0
OTSO
NVSO
SPSO
JNSI
MYSI
SPSI
JNSO
AGSI
MRSI
NVSI
OTSI
JL SO
DC SI
JLSI
DCSI
JLSO

Figure 6. Variation in percentages of particles retained by 35 mesh (0.5 mm), 60 mesh (0.25 mm), 120 mesh (0.125 mm) and 230 mesh (0.0625 mm) sieves among the six sites over sampling time. Dry weights were used to calculate the percentages.


35 MESH
PERCENT
0
10
20
30
40
SITE
6
5
4
3
2
1
DATE
30JUN80
22DEC80
15JUN81
08DEC81


60 MESH
PERCENT
0
30
60
90
SITE
6
5
4
3
2
1
DATE
30JUN80
22DEC80
15JUN81
08DEC81


120 MESH
PERCENT
0
10
20
30
SITE
6
5
4
3
2
1
DATE
30JUN80
22DEC80
15JUN81
08DEC81

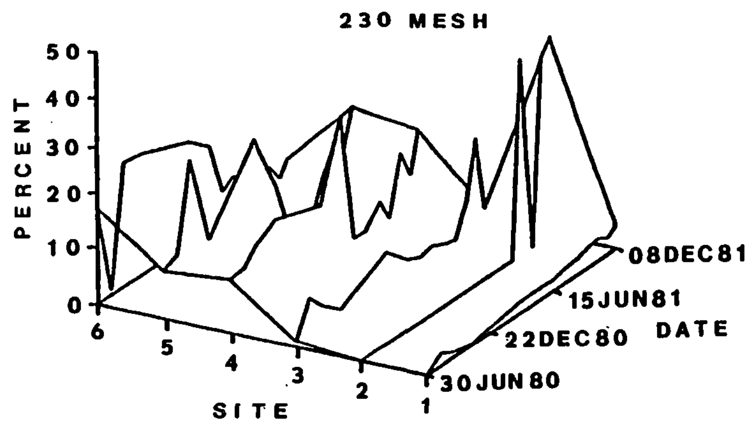
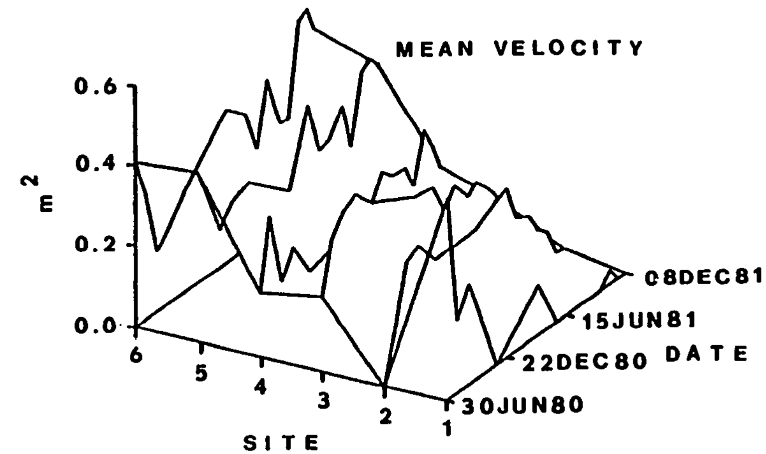
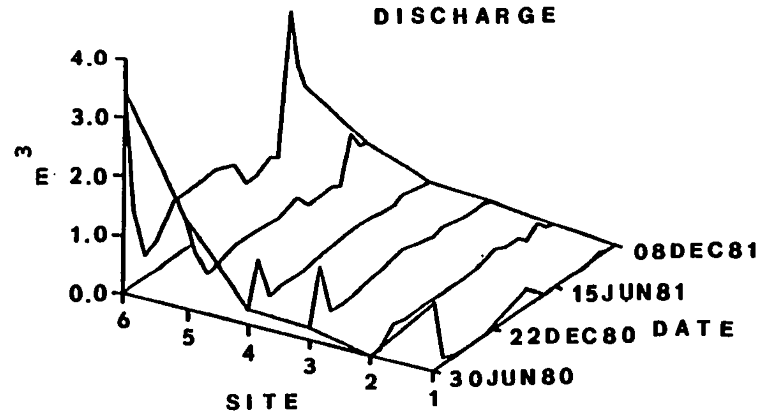
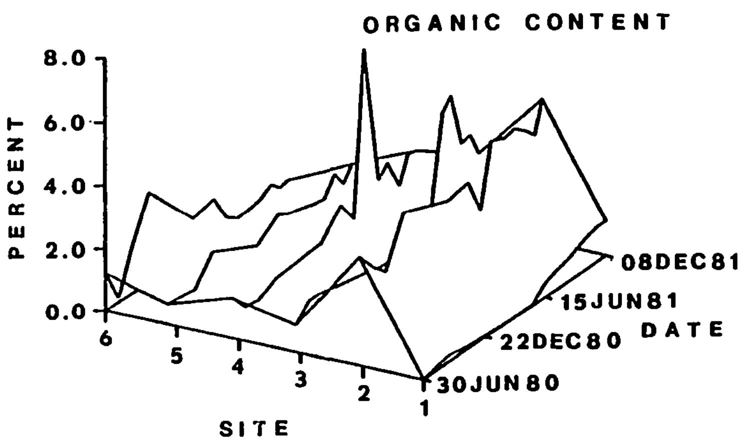

230 MESH
PERCENT
0
10
20
30
40
50
SITE
6
5
4
3
2
1
DATE
30JUN80
22DEC80
15JUN81
08DEC81

Figure 7. Variation in total average stream velocity, discharge, organic content of sediments and stream turbidity among sites over sampling time.


MEAN VELOCITY
0.6
0.4
0.2
0.0
m2
6
5
4
3
2
1
SITE
08DEC81
15JUN81
22DEC80
30JUN80
DATE


DISCHARGE
4.0
3.0
2.0
1.0
0.0
m3
6
5
4
3
2
1
SITE
08DEC81
15JUN81
22DEC80
30JUN80
DATE


ORGANIC CONTENT
8.0
6.0
4.0
2.0
0.0
PERCENT
6
5
4
3
2
1
SITE
08DEC81
15JUN81
22DEC80
30JUN80
DATE

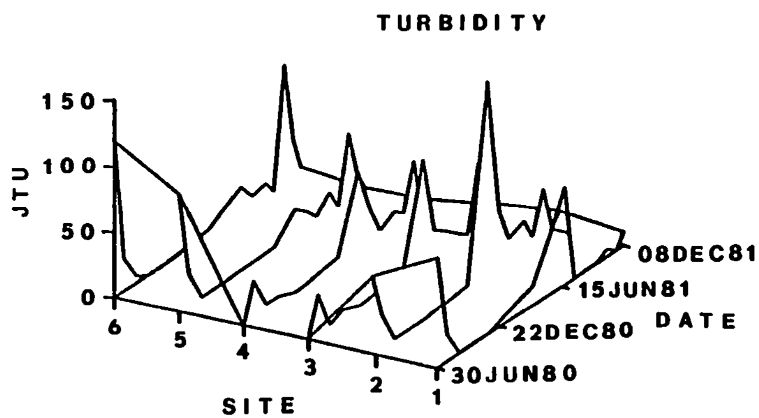
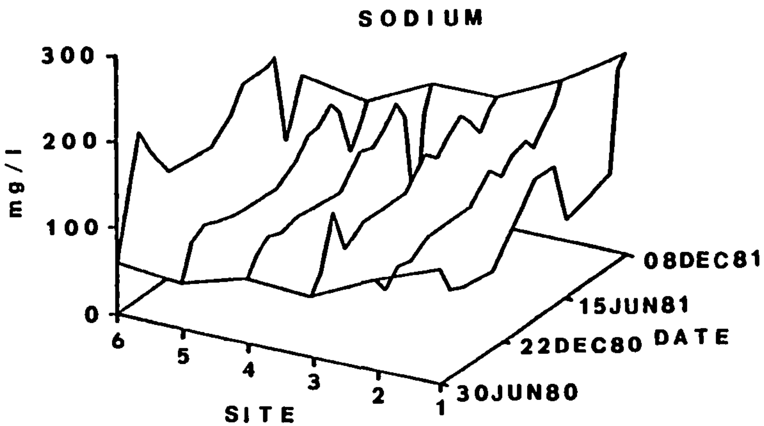
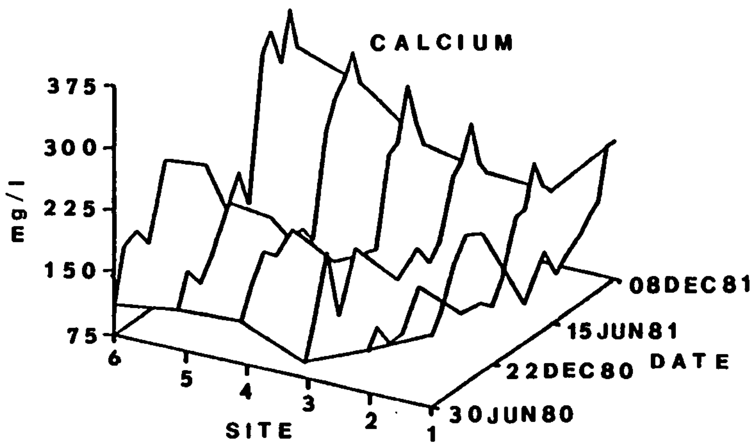
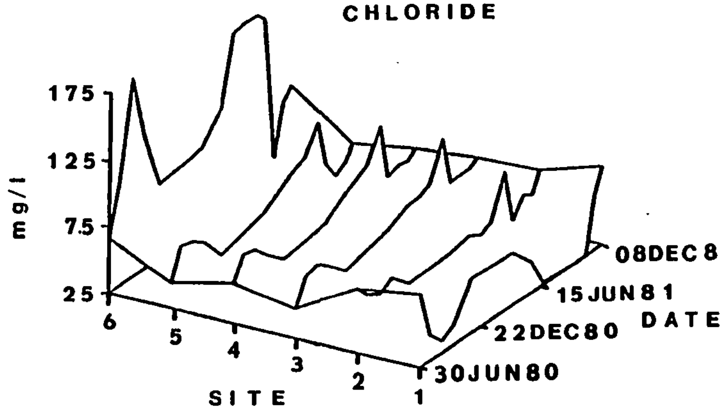

TURBIDITY
150
100
50
0
JTU
6
5
4
3
2
1
SITE
08DEC81
15JUN81
22DEC80
30JUN80
DATE

Figure 8. Variation in the concentrations of major salts in the Washita River among sites over sampling time.


SODIUM
300
200
100
0
mg/l
6
5
4
3
2
1
SITE
08DEC81
15JUN81
22DEC80
30JUN80
DATE


CALCIUM
375
300
225
150
75
mg/l
6
5
4
3
2
1
SITE
08DEC81
15JUN81
22DEC80
30JUN80
DATE


CHLORIDE
175
125
75
25
mg/l
6
5
4
3
2
1
SITE
08DEC81
15JUN81
22DEC80
30JUN80
DATE

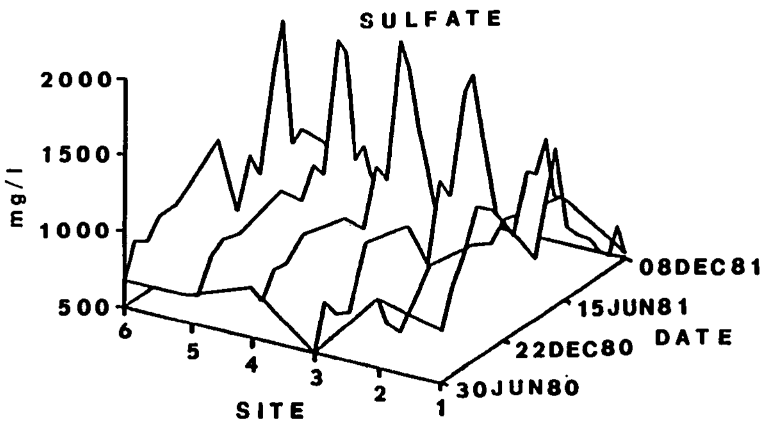
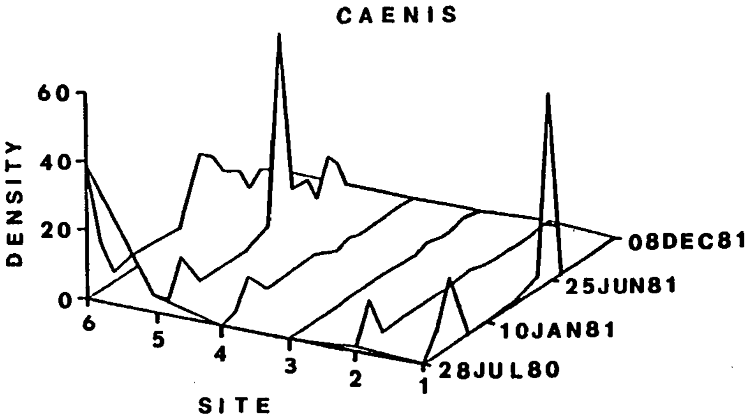
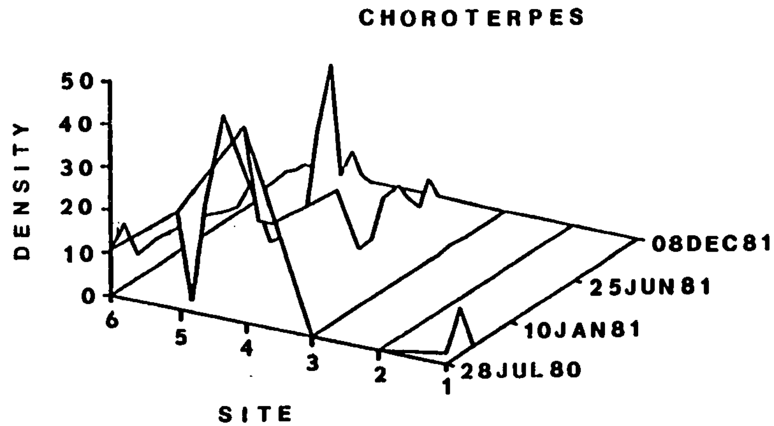
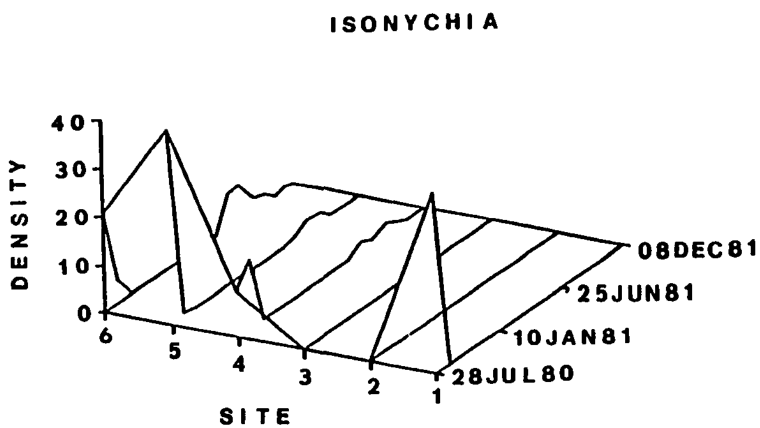

SULFATE
2000
1500
1000
500
mg/l
6
5
4
3
2
1
SITE
08DEC81
15JUN81
22DEC80
30JUN80
DATE

Figure 9. Variation of epifaunal densities of *Caenis*, *Choroterpes*, *Isonychia* and *Tricorythodes* on Dendy samplers among the sites over sampling time. Densities are expressed as the average number of organisms per Dendy sampler.


CAENIS
DENSITY
60
40
20
0
SITE
6
5
4
3
2
1
28JUL80
10JAN81
25JUN81
08DEC81


CHOROTERPES
DENSITY
50
40
30
20
10
0
SITE
6
5
4
3
2
1
28JUL80
10JAN81
25JUN81
08DEC81


ISONYCHIA
DENSITY
40
30
20
10
0
SITE
6
5
4
3
2
1
28JUL80
10JAN81
25JUN81
08DEC81

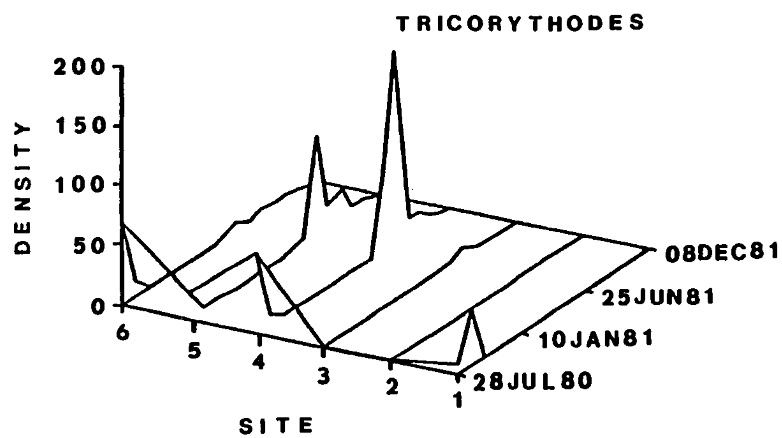
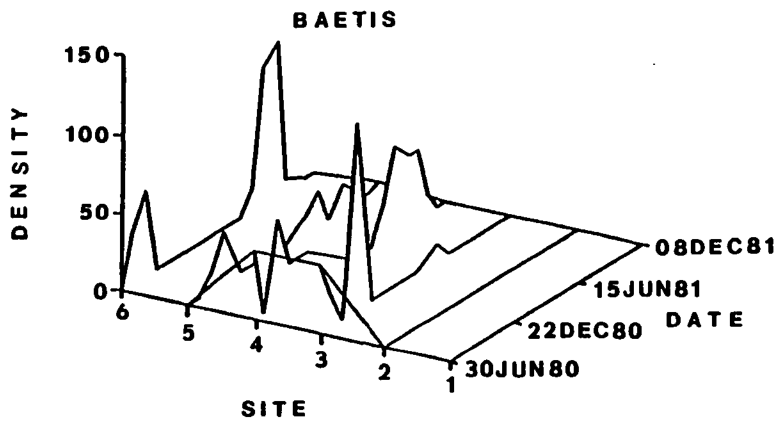
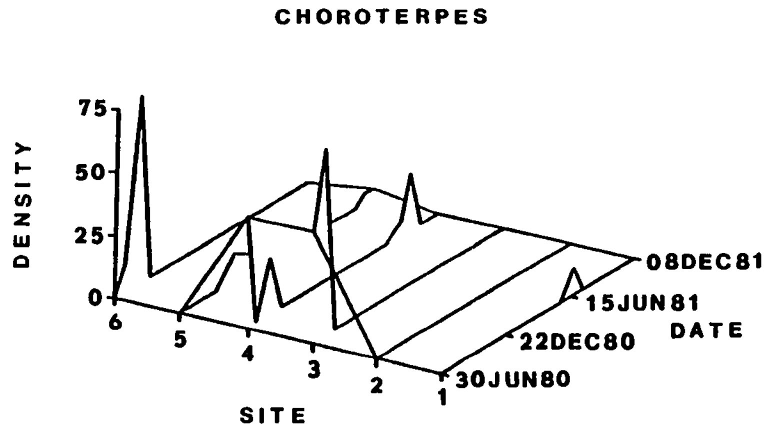
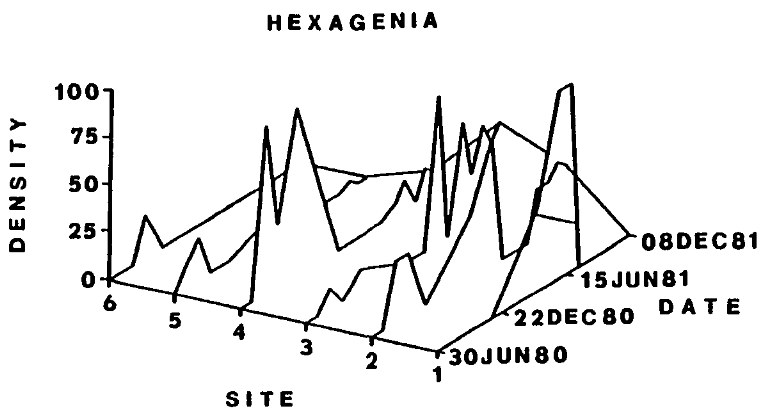

TRICORYTHODES
DENSITY
200
150
100
50
0
SITE
6
5
4
3
2
1
28JUL80
10JAN81
25JUN81
08DEC81

Figure 10. Variation of infaunal densities of *Baetis*, *Choroterpes*, *Hexagenia* and *Tricorythodes* from dredge samples. Densities are expressed as the average number of organisms per square meter.


BAETIS
DENSITY
150
100
50
0
SITE
6
5
4
3
2
1
DATE
30JUN80
22DEC80
15JUN81
08DEC81


CHOROTERPES
DENSITY
75
50
25
0
SITE
6
5
4
3
2
1
DATE
30JUN80
22DEC80
15JUN81
08DEC81


HEXAGENIA
DENSITY
100
75
50
25
0
SITE
6
5
4
3
2
1
DATE
30JUN80
22DEC80
15JUN81
08DEC81

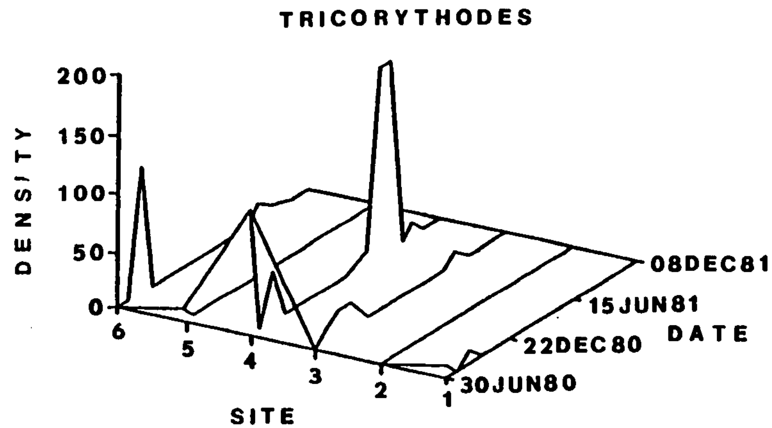

TRICORYTHODES
DENSITY
200
150
100
50
0
SITE
6
5
4
3
2
1
DATE
30JUN80
22DEC80
15JUN81
08DEC81

Table 1. Representative levels of percentage dissolved oxygen saturation at six sites in the Washita River. The mean values are calculated from 14 sampling periods between June 1980 and December 1981.

Date	Site					
	1	2	3	4	5	6
July 1980	120.6	110.5	100.5	109.4	114.2	112.6
March 1981	101.6	98.5	110.2	109.8	150.8	133.4
September 1981	90.3	99.6	93.2	84.2	106.7	142.4
November 1981	69.5	104.0	92.7	92.2	85.3	87.2
Grand mean	81.8	103.0	99.5	95.1	104.5	113.2
± Standard Error	17.5	7.4	8.5	9.2	18.0	17.8

Table 2. Multiple regression of variables on dimensions for representative sampling times for individual time spaces for physical variables. The regression weights are normalized to equal direction cosines. D# = dimension number.

Variable	28 JULY 1980			19 MAY 1981		
	D1	D2	R^2	D1	D2	R^2
Turbidity	0.950	0.313	0.45	-0.372	-0.928	0.96
Water Temperature	-0.884	-0.468	0.50	-0.102	-0.995	0.78
Mean Velocity	-0.113	0.993	0.67	-0.500	0.861	0.83
Surface Velocity	-0.169	0.986	0.63	-0.519	0.857	0.88
Bottom Velocity	-0.044	0.984	0.73	-0.488	0.878	0.72
Discharge	-0.432	0.902	0.78	-0.258	0.966	0.95
Organic Content	-0.979	-0.205	0.66	-0.914	-0.405	0.54
> 5 mesh (4.0 mm)	-0.916	0.401	0.06	-0.999	0.040	0.13
> 10 mesh (2.0 mm)	-0.882	0.472	0.25	-0.912	0.125	0.03
> 18 mesh (1.0 mm)	-0.645	0.764	0.19	0.995	-0.104	0.09
> 35 mesh (0.5 mm)	0.906	0.423	0.26	0.955	-0.297	0.80
> 60 mesh (0.25 mm)	0.998	0.062	0.83	0.870	0.493	0.80
> 120 mesh (0.125 mm)	0.278	0.961	0.75	0.026	1.000	0.80
> 230 mesh (0.0625 mm)	-0.087	0.996	0.84	0.075	0.997	0.34
< 230 mesh (0.0625 mm)	-0.851	-0.525	0.62	-0.537	-0.843	0.63

Table 2. Continued.

Variable	21 JULY 1981			16 NOVEMBER 1981		
	D1	D2	R^2	D1	D2	R^2
Turbidity	-0.994	-0.111	0.88	-0.552	0.834	0.71
Water Temperature	-0.752	0.664	0.02	-0.945	-0.336	0.97
Mean Velocity	-0.758	0.652	0.98	-0.270	0.963	0.96
Surface Velocity	-0.781	0.624	0.97	-0.288	0.958	0.98
Bottom Velocity	-0.730	0.683	0.91	-0.245	0.970	0.91
Discharge	-0.841	0.541	0.97	-0.276	0.962	0.83
Organic Content	-0.752	-0.659	0.23	-0.798	-0.603	0.92
> 5 mesh (4.0 mm)	-0.996	0.089	0.08	-0.988	0.155	0.14
> 10 mesh (2.0 mm)	-0.925	0.380	0.00	-0.945	0.328	0.13
> 18 mesh (1.0 mm)	0.983	0.182	0.16	0.520	0.854	0.17
> 35 mesh (0.5 mm)	0.997	0.082	0.37	0.963	0.267	0.76
> 60 mesh (0.25 mm)	0.978	0.207	0.79	0.925	0.379	0.95
> 120 mesh (0.125 mm)	0.512	0.859	0.59	0.864	0.504	0.89
> 230 mesh (0.0625 mm)	0.432	0.902	0.53	-0.895	-0.446	0.94
< 230 mesh (0.0625 mm)	-0.931	-0.364	0.78	-0.995	0.104	0.50

Table 3. Multiple regression of variables for representative sampling times for individual time spaces for chemcial variables. The regression weights are normalized to equal direction cosines. D# = dimension number.

Variable	28 JULY 1980			06 OCTOBER 1980		
	D1	D2	R^2	D1	D2	R^2
Calcium	0.392	-0.920	0.88	-0.050	-0.999	0.72
Sulfate	0.052	-0.999	0.79	-0.020	-1.000	0.93
Sodium	0.873	-0.488	0.95	0.988	-0.059	0.83
Chloride	0.929	0.370	0.87	0.991	0.136	0.78
Conductivity	0.846	0.533	0.54	0.450	-0.893	0.98
pH	0.963	-0.271	0.37	-0.614	0.789	0.30

Variable	29 AUGUST 1981			22 SEPTEMBER 1981		
	D1	D2	R^2	D1	D2	R^2
Calcium	0.983	0.184	0.98	0.975	0.221	0.98
Sulfate	0.395	0.919	0.80	0.513	0.859	0.97
Sodium	0.783	0.622	0.75	0.783	0.622	0.75
Chloride	0.856	0.517	0.88	0.978	0.210	0.89
Conductivity	0.454	0.891	0.96	0.519	0.855	0.99
pH	0.925	-0.435	0.38	0.657	-0.754	0.63

Table 4. Kendall's rank correlation of all dimensions from the composite physical, chemical, dredge and Dendy ordinations. The values given are: Tau B coefficient / Probability > |R| .

		Dendy		Dredge		Chemical		Physical	
		D1	D2	D1	D2	D1	D2	D1	D2
Dendy	D1								
	D2	0.3333							
		0.3476							
Dredge	D1	-0.0667	0.3333						
		0.8510	0.3476						
	D2	0.8667	0.4667	0.0667					
		0.0146	0.1885	0.8510					
Chemical	D1	-0.6000	-0.2000	-0.3333	-0.7333				
		0.0909	0.5730	0.3476	0.0388				
	D2	0.2000	0.0667	-0.6000	0.3333	-0.0667			
		0.5730	0.8510	0.0909	0.3476	0.8510			
Physical	D1	-0.3333	0.0667	0.2000	-0.4667	0.4667	-0.6000		
		0.3476	0.8510	0.5730	0.1885	0.1885	0.0909		
	D2	-0.6000	-0.2000	-0.3333	-0.7333	1.0000	-0.0667	0.4667	
		0.0909	0.5730	0.3476	0.0388	0.0048	0.8510	0.1885	