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INFLUENCE OF GEOMORPHOLOGICAL ORIGIN UPON MACROINVERTEBRATE COMMUNITY STRUCTURE IN BLACK HILLS STREAMS

BY

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INFLUENCE OF GEOMORPHOLOGICAL ORIGIN UPON MACROINVERTEBRATE COMMUNITY STRUCTURE IN BLACK HILLS STREAMS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached are necessarily the conclusions of the major department.

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INFLUENCE OF GEOMORPHOLOGICAL ORIGIN UPON MACROINVERTEBRATE COMMUNITY STRUCTURE IN BLACK HILLS STREAMS

Abstract

Matthew Lechner

The purpose of this study was to test a stream classification system proposed for the Black Hills National Forest. Stream physiochemical characteristics and macroinvertebrate community structure were compared among three geomorphically distinct landtype associations in the Black Hills. Stepwise disciminant analysis identified five physiochemical variables, which explained 90% of the variabilty among landtype associations. The classificatory discriminant procedure correctly reclassified 47 of 52 stations based on the five discriminating invertebrate taxa. Each landtype association was sufficiently different in stream physiochemical characteristics to permit classification. Macroinvertebrates exhibited distributional patterns related to changes in geomorphic structure and stream order, among landtype associations. Streams among landtype associations differed in physiochemical characteristics, size, and macroinvertebrate community structure. The Crystalline Canyonlands were dominated by larger order streams, with lower quality invertebrate habitat, associated with geomorphic structure and stream position in the drainage pattern. Macroinvertebrate community structure was different in the Crystalline Canyonlands than in the Moderately Rolling Uplands and Gently Dipping Plateaulands. The Gently Dipping Plateauland and Moderately Rolling Upland streams were similar in physiochemical composition, size, and macroinvertebrate community structure. Macroinvertebrate standing biomass and richness differed within streams among landtype associations. Stream order and geomorphic structure acted synergistically in structuring stream ecosystems in the Black Hills. The landtype association level of classification is appropiate for detecting differences among streams.

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INTRODUCTION

The evolution of landforms and the development of streams occur simultaneously. Most landforms are sculptured by the corrosive and erosive action of flowing waters. The erosion of landforms influences the physical and chemical characteristics of streams (Platts 1979). Drainage basin geology influences soil, slope, and hydrology (Strayer 1983). Therefore, geology effects the physiochemical stream environment. Differences in the physiochemical properties of a stream must necessarily impact the composition and production of stream biota.

Aquatic macroinvertebrate distribution is dependent upon the stream environment, with each taxa being located within a definite range of physiochemical conditions (Winget and Mangum 1979). Macroinvertebrate composition (Cummins 1979), richness (Winget and Mangum 1979), and production (Hynes 1970) may be influenced by physiochemical stream properties. Thus, macroinvertebrate community structure may be used as an indicator of various watershed influences.

Macroinvertebrate community structure represents an ecological response to varying conditions within the environment. Therefore, biotic response of macroinvertebrates to physiochemical stream conditions may be utilized to categorize or classify streams based on similarities in community structure. Similar streams should respond in a like manner to a management activity that stresses the stream (Lotspeich and Platts 1982). Grouping streams based on similarities will enable managers to protect and enhance stream resources in relation to proposed management activities.

Organization of information using a classification system can increase our capability to predict and eliminate stresses placed on streams by various management activities. The land-aquatic classification system proposed by Lotspeich and Platts (1982) was adapted for use in the Black Hills of South Dakota. A hierarchial system, based on the ecosystem concept, this classification scheme stresses the integration of aquatic and terrestrial resources to form the basic ecosystem. It describes the processes that determine structure and influence the productivity of an ecosystem. The interrelationship of geology and climate as causative agents in ecosystem formation is stressed. This system accounts for biotic and ecological differences, among land classes, by grouping classes based on their geologic origin.

The purpose of this study was to test the classification system proposed for the Black Hills of South Dakota. The landtype association level of classification was chosen for this study. At this hierarchial level, geology influences landforms and streams under an identical macroclimate. Macroinvertebrate community structure should reflect a response to environmental conditions, influenced by drainage basin geology, at this level of classification. The objective of this study was to determine whether macroinvertebrate community structure differs among streams draining different landtype associations in the Black Hills National Forest. The analysis was designed to determine whether streams draining different landtype associations: (1) differed in physiochemical composition, and (2) differed in macroinvertebrate distribution, standing biomass, and richness.

STUDY AREA

The study area was located in the Black Hills National Forest. The boundaries of the forest include most of the Black Hills, a mountainous area located in extreme west-central South Dakota and eastern Wyoming (Figure 1). The Black Hills are an isolated, unglaciated, and diverse group of mountains. An extensive forest of ponderosa pine (*Pinus ponderosa*) covers most of the Black Hills. The forest is managed for multiple uses including logging, mining, livestock grazing, consumptive and non-consumptive wildlife uses, recreation, and agriculture (Forest Service 1983).

The classification scheme developed for the Black Hills National Forest is a hierarchial system consisting of six intensity levels (Figure 2). The entire Black Hills area was mapped to the landtype association level of classification, based on the system of Lotspeich and Platts (1982). Lynn *et al*. (no date) categorized the entire Black Hills National Forest into 15 distinct land classes termed ecological land units. The classification criteria used in their study was nearly identical to the landtype association classification level of Lotspeich and

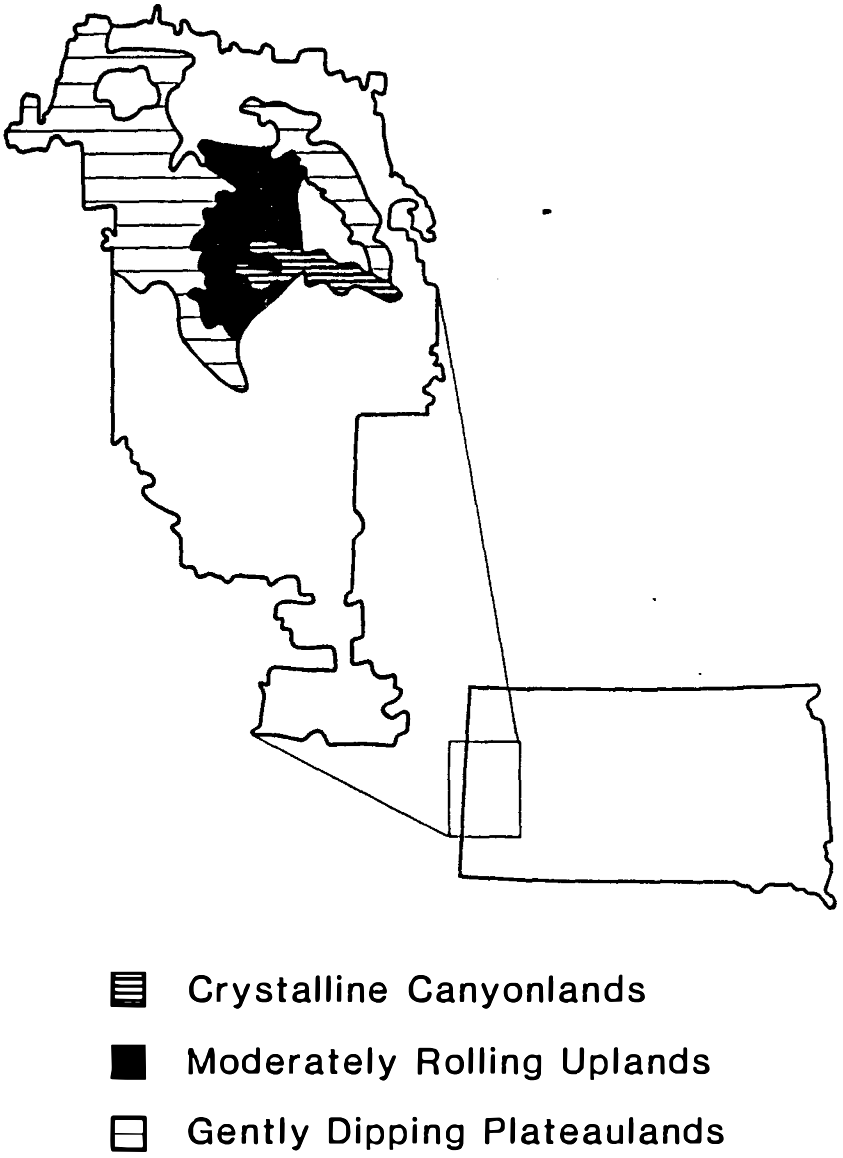

Figure 1. Study area location in the Black Hills National Forest, South Dakota and the three landtype associations studied during 1984 and 1985.

DOMAIN: Dry
  DIVISION: Steppe
    PROVINCE: Great Plains Short Grass Prairie
      SECTION: Wheatgrass - Needlegrass
      SUBSECTION: Low Mountains
        LANDTYPE ASSOCIATION:
          Limestone Canyonlands
          * Crystalline Canyonlands
          * Gently Dipping Plateaulands
          * Moderately Rolling Uplands
          Crystalline Hill and Ridgelands
          Volcanic Hill and Ridgelands
          Domelike Hills
          Gently Rolling Uplands
          Steeply Dipping Plateaulands
          Valley Lands
          Sundance Uplands
          Steeply Dipping Hogbacks
          Gently Dipping Hogbacks
          Depositional Lands
          Bottom Lands.

* landtype associations selected for this study

Figure 2. Classification system proposed for the Black Hills of South Dakota.

Platts (1982). Therefore, the ecological land units were considered synonymous with landtype associations. Three landtype associations were selected for this study (Figure 1.) and were chosen based on the number of streams, diversity of geology, and resource importance.

The Gently Dipping Plateaulands range in elevation from 1260 to 2070 m above sea level (masl). The area is mountainous with broad ridgetops and gently to strongly dipping sideslopes. Valleys are narrow and slope gradients range from 10-25%. Average precipitation is 51-66 cm/year. The bedrock is mainly Pahasapa Limestone with some shale and sandstone interspersed.

The Gently Dipping Plateaulands are higher in elevation than the Moderately Rolling Uplands (1590-1830 masl) but the topography is similar. Valleys of the Moderately Rolling Uplands are broad and slope gradients range from 10-25%. Average precipitation is 46-56 cm/yr. Bedrock of the Moderately Rolling Uplands consists primarily of slate and mica schist.

The Crystalline Canyonlands range in elevation from 1220 to 1770 (masl) and slope gradients range from 40-50%. This area is interspersed with rocky ridges, broad valleys and granite outcroppings. Granite is the dominant bedrock with slate and mica schist interspersed. Average precipitation in the Crystalline Canyonlands is 51-56 cm/yr.

METHODS

Station Selection

A stratified random technique was employed to select stations. Stations were selected to reduce influence of human and livestock activities. A total of 74 sites (37 paired stations) were selected for biological and physiochemical sampling. Stations were stratified among landtype associations and soil types. All soil types represented by individual lengths greater than 1000m were included in the selection process for each landtype association. All contiguous 1000m stream sections per soil type were delineated and numbered on United States Geological Survey 7.5 minute series topographic maps. From these numbered sections, a random selection was made, whereby each soil type was represented in the sampling scheme. Where possible two alternative sites were selected for each paired station. Alternate sites were sampled when the primary site was impacted by human activity (i.e. past or present mining activities, extensive cattle grazing, logging, etc.). Two stations, 200m apart, were sampled at each site, for each soil type present. Sites were located at approximately the middle of the 1000m soil type section. Individual collection stations were located 100m upstream and downstream of the station midpoint. Legal descriptions for each site are presented in Appendix Table A. The order of each stream was assigned according to the contour crenulation method (Gregary 1966).

Invertebrate Collection and Processing

Quantitative macroinvertebrate samples were collected between 2-15 August, 1984 and between 1-4 August, 1985. A total of 74 sites (37 paired stations) were selected for biological and physiochemical sampling. Due to drought conditions during the summer of 1985 only 57 sites (28.5 paired stations) were sampled. The remaining 17 sites were either dry or impacted (due to extensive cattle grazing or mining activity). Invertebrates were collected from midstream riffle sections, using a Winget modified Surber sampler (Reichart 1975). At each site three replicate samples were collected. Samples were sieved in the field (500 um sieve), preserved in 70% ethanol, and stained with Rose Bengal to aid in sorting.

Due to the large number of samples to be processed a subsampling method was employed. Samples were divided into eight equal cells using a motorized subsampler (Waters 1969). A minimum of 300 invertebrates were sorted from each sample. Invertebrates were hand sorted using binocular microscopes (10X and 0.7 to 4.2 objectives) and placed in vials with 70% ethanol for identification, enumeration, and biomass determination. Organisms were identified to genera where possible. Due to time constraints some organisms were only identified to the familial level. For each replicate sample, wet weight biomass estimates were obtained for each taxa. Taxa were weighed to the nearest 0.001g using an Ohaus Galaxy model 400D top loading electronic balance.

Physiochemical measurements

Physiochemical sampling was conducted in conjunction with biological sampling. The line transect method (Platts *et al*. 1983) was used to collect morphometry data. At each transect the following physical parameters were estimated: stream width (nearest 3.05 cm), stream depth (nearest 3.05 cm), instream cover (nearest 0.305m), percent substrate type, stream flow (m^3/second) and percent substrate embeddedness. Channel gradients were taken using a surveyors level and statia rod. Channel gradients were recorded as % slope.

All water quality data were collected using standard methods. At each site conductivity (umhos/cm), temperature (c), and pH were determined in the field.

Dissolved oxygen (mg/l) was measured in 1984 and found to be at or near saturation for all streams sampled. Therefore, it was not measured in 1985. A water sample was collected and stored on ice for laboratory analysis. Alkalinity (mg/l as CaCO3) and turbidity (NTU) analyses were performed at the Game, Fish and Parks water quality laboratory in Rapid City, South Dakota. Analytical analyses of orthophosphates (mg/l), nitrates (mg/l), and sulfates (mg/l) were obtained through contract services with Travis Laboratories in Rapid City, South Dakota.

Physiochemical Analysis

Discriminant analysis was employed using the Statistical Analysis System (SAS Institute Inc. 1985) to determine whether landtype associations could be separated using quantitative values of the physiochemical variables. Stepwise discriminant analysis was utilized to identify the subset of variables that best revealed differences among landtype associations. Landtype associations were utilized as discrete dependent variables and there were 17 continuous independent variables, from 52 stations (Table 1). Five of 57 total stations were omitted from the analysis due to missing values. Major discriminating variables were then subjected to

Table 1. Independent variables used for stepwise discriminant analysis of physiochemical composition in Black Hills streams. Data collected during August (7-15),1985 and August (1-4),1985.

Variable	Units of Measurement
Landtype Association	Discrete variable
Gradient	% Slope
Stream Depth	3.05 cm
Stream Flow	m^3/Second
Instream Cover	Nearest 0.305 m
Large Boulder	Nearest 0.305 m
Small Boulder	Nearest 0.305 m
Rubble	Nearest 0.305 m
Gravel	Nearest 0.305 m
Large Sediment	Nearest 0.305 m
Small Sediment	Nearest 0.305 m
Turbidity	Nitrozine Turbidity Units
pH	pH scale
Conductivity	umhos/cm
Alkalinity	mg/l
Sulfate	mg/l
Nitrates	mg/l
Phosphates	mg/l

classificatory discriminant analysis, which was utilized to determine whether individual stream stations could be grouped into the proper landtype association based on the major discriminating variables. One-way analysis of variance (ANOVA) was used to determine whether significant ($P \geq 0.05$) differences occurred in the major discriminating variables among landtype associations. The 95% confidence intervals were employed to identify where differences occurred among landtype associations.

The predicted community tolerance quotient (PCTQ) of the Biotic Condition Index (Winget and Mangum 1979) is an expression of what the invertebrate community condition in a stream should be under the environmental conditions present, as defined by the determinant values. For this study, the PCTQ was utilized to determine whether streams differed in potential for invertebrate production among landtype associations. Because invertebrate production is related to stream order (Vannote *et al*. 1980), all comparisons of the PCTQ, invertebrate standing biomass and richness were stratified by stream order. A one-way ANOVA was utilized to compare flows among fifth and sixth order streams. No significant differences ($P \leq 0.05$) were found. Therefore, fifth and sixth order streams were combined to strengthen the design (Table 2). Because of missing cells, valid comparisons were limited. Comparisons were performed among fifth and sixth order streams in all landtype associations and seventh order streams among the Crystalline Canyonlands and the Gently Dipping Plateaulands. Nested ANOVA was employed to compare the PCTQ among landtype associations.

Invertebrate Analysis

Cluster analysis, based on presence and absence of 71 taxa at each station, was utilized to examine invertebrate distribution patterns. Only those taxa present at 5% or more of the stations in any landtype association were included as variables in the cluster analysis. Clustering was accomplished using the unpaired group arithmetic average clustering method (Sneath and Sokal 1973). The Bray-Curtis similarity index was employed to determine pair similarity (Bray and Curtis 1957).

Stepwise discriminant analysis was utilized to identify a subset of taxa which best revealed differences among landtype associations. Landtype associations were used as discrete dependent variables and mean standing biomass estimates of 46 taxa were used as independent variables. Major discriminating

Table 2. Statistical design of macroinvertebrate study in the Black Hills of South Dakota. Number of stations in each landtype association is presented stratified by stream order.

	LANDTYPE ASSOCIATIONS		
Stream Order[a]	Crystalline Canyonlands	Moderately Rolling Uplands	Gently Dipping Plateaulands
5	1	10	14
6	2	6	4
7	8	0	4
8	8	0	0
Totals	19	16	22

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[a] Fifth and sixth order streams were grouped to strengthen the design.

taxa, from the stepwise discriminant analysis, were subjected to classificatory discriminant analysis to determine whether stations could be grouped with the proper landtype association based on major discriminating taxa.

Macroinvertebrate standing biomass (mean total at each station) and invertebrate richness (number of taxa per station) were evaluated to examine macroinvertebrate communities for differences among landtype associations. Comparisons were stratified by stream order. Nested ANOVA was employed to compare macroinvertebrate biomass among landtype associations. The 95% confidence intervals were utilized to determine where differences occurred. Chi-square analysis was utilized to test for differences in macroinvertebrate richness among landtype associations.

RESULTS

Physiochemical Analysis

Five of 17 physiochemical variables subjected to stepwise discriminant analysis accounted for 90.3% of the variability among landtype associations. Sulfate, which was the major discriminating variable, accounted for 76.3% of the among-group variability. The remaining variables and variation explained include: instream cover, 5.6%, phosphate, 3.6%, turbidity, 2.3%, and alkalinity, 2.5%. Discriminant reclassification procedure, using the above variables, correctly classified 47 of the 52 stations (Table 3). All Crystalline Canyonland and Moderately Rolling Upland stations were correctly classified. Five of 21 stations from the Gently Dipping Plateaulands were misclassified. Four stations were incorrectly grouped with the Moderately Rolling Uplands and one station was incorrectly grouped with the Crystalline Canyonlands.

Major discriminating variables were subjected to a one-way analysis of variance. Significant ($P \geq 0.05$) differences were found in mean values for sulfate, instream cover, phosphate, turbidity, and alkalinity among landtype associations. The 95% confidence intervals were used to determine where differences occurred (Table 4). Sulfate levels were

Table 3. Classificatory discriminant analysis of 52 stations, from three landtype associations in the Black Hills of South Dakota. The analysis was based on mean values of sulfate, instream cover, phosphate, turbidity, and alkalinity.[a]

	Landtype Associations		
Landtype Association	Crystalline Canyonlands	Moderately Rolling Uplands	Gently Dipping Plateaulands
Crystalline Canyonlands	17 100.00%	0 0.00%	0 0.00%
Moderately Rolling Uplands	0 0.00%	0 0.00%	14 100.00%
Gently Dipping Plateaulands	1 4.76%	4 19.05%	16 76.19%

[a] 5 of 57 observations not included in the analysis due to missing values.

Table 4. Means and 95% confidence intervals for major discriminating physiochemical variables among streams draining three landtype associations in the Black Hills of South Dakota. Data collected during August (2-15) 1984 and August (1-4),1985.

	Landtype Association		
Physiochemical Variable	Crystalline Canyonlands	Moderately Rolling Uplands	Gently Dipping Plateaulands
Sulphate (mg/l)	12.60 ± 1.74^{a}	2.91 ± 1.56^{b}	1.51 ± 0.724^{b}
Instream Cover (ft.)	0.719 ± 0.411^{a}	1.23 ± 0.990^{ab}	3.18 ± 1.67^{b}
Ortho-Phosphate (mg/l)	0.140 ± 0.004^{a}	0.024 ± 0.005^{b}	0.015 ± 0.003^{c}
Turbidity (NTU)	1.79 ± 0.816^{a}	4.94 ± 1.74^{b}	1.32 ± 0.891^{a}
Alkalinity (mg/l)	170.0 ± 18.4^{a}	181.0 ± 29.4^{ab}	220.0 ± 15.6^{c}

^{a},^{b}, or ^{c} denotes significant difference among landtype associations.

significantly ($P \geq 0.05$) higher in the Crystalline Canyonlands than in either the Moderately Rolling Uplands or the Gently Dipping Plateaulands. Instream cover was significantly ($P \geq 0.05$) higher in the Gently Dipping Plateaulands and Moderately Rolling Uplands than in the Crystalline Canyonlands. Mean values for phosphates and alkalinity were significantly ($P \geq 0.05$) different among all landtype associations. Significantly ($P \geq 0.05$) higher turbidity levels were found in the Moderately Rolling Uplands. Raw chemical data is presented in Appendix Table B. Nested analysis of variance among PCTQ values indicated that differences occurred in invertebrate habitat suitability of streams draining different landtype associations. Gradient data was available for only one fifth-sixth order stream station in the Crystalline Canyonlands, therefore the PCTQ was only calculated for this one station. The PCTQ for this station was higher than for the Moderately Rolling Uplands and the Gently Dipping Plateaulands but no test of significance was performed on this one value. Nested ANOVA revealed no significant ($P \leq 0.05$) differences in the PCTQ in fifth and sixth order stream stations among the Moderately Rolling Uplands and the Gently Dipping Plateaulands. Mean values and the 95% confidence intervals for the PCTQ were 66 (no confidence interval), 53.3 ± 2.5, and 53.8 ± 2.4, for the Crystalline Canyonlands, Moderately Rolling Uplands, and the Gently Dipping Plateaulands respectively. Nested ANOVA revealed a significant ($P \geq 0.05$) difference in PCTQ for seventh order streams among the Crystalline Canyonlands and the Gently Dipping Plateaulands. Mean values and the 95% confidence intervals for the Crystalline Canyonlands and the Gently Dipping Plateaulands were 55.2 ± 2.5 and 50.8 ± 2.0, respectively.

Invertebrate Analysis

A composite list of macroinvertebrate taxa collected is presented in Appendix Table C. Cluster analysis, based on presence and absence of 71 invertebrate taxa, divided the stations into three clusters (Figure 3). At 56.0% similarity, the second cluster consisted of 89.5% of the Crystalline Canyonland stations. No stations from the Gently Dipping Plateaulands or the Moderately Rolling Uplands were linked with this cluster until the 54% similarity level. Stations from the Gently Dipping Plateaulands and the Moderately Rolling Uplands were intermixed throughout the remaining two clusters. Ten stations from the Gently Dipping Plateaulands were linked together at the 61% similarity

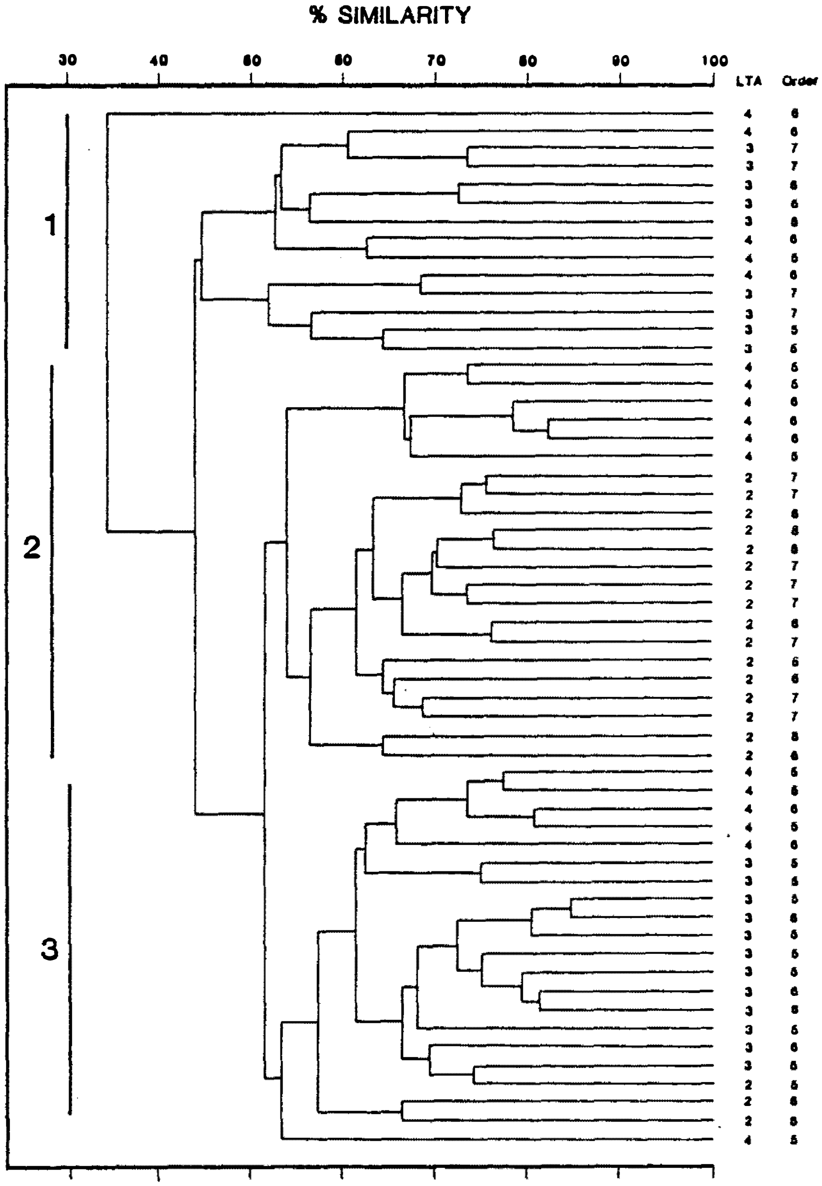

Figure 3. Bray-Curtis Similarity Index cluster dendogram of 57 stream stations, based on presence and absence of 71 invertebrate taxa. Landtype association (LTA). Stream order (ORDER).

level. Overall clustering indicated that macroinvertebrate community structure was similar among stations in the Moderately Rolling Uplands and the Gently Dipping Plateaulands.

Stepwise discriminant analysis identified 10 taxa which accounted for 93.8% of the variability among landtype associations. Chloroperlidae, which was the major discriminating taxon, explained 38.4% of the variability among landtype associations. The amount of the among-group variability explained by the remaining nine major discriminating taxa follows: Empididae, 6.2%, *Brachtycentrus,* 9.5%, *Petrophila,* 9.3%, Straitomyidae, 5.3%, Hydropsycidae, 9.8%, *Glossosoma,* 4.2%, *Luecotricha,* 5.7%, *Helicopsyche,* 2.8%, *Paraleptophelbia,* 2.6%. Based on these 10 taxa, the classificatory discriminant analysis procedure correctly classified 86.0% of the stations (Table 5). Fourteen of 19 Crystalline Canyonland stations (73.7%) were correctly classified. Five Crystalline Canyonland stations were incorrectly grouped with the Gently Dipping Plateaulands. Twenty-one of 22 Gently Dipping Plateauland stations (95.5%) were correctly classified. One Gently Dipping Plateauland station was incorrectly classified with the Crystalline Canyonlands. Fourteen of 16 Moderately Rolling Upland

Table 5. Classificatory discriminant analysis of 57 stream stations from three landtype associations in the Black Hills of South Dakota. The analysis was based on biomass estimates of 10 macroinvertebrate taxa.

	Landtype Association		
Landtype Associations	Crystalline Canyonlands	Moderately Rolling Uplands	Gently Dipping Plateaulands
Crystalline Canyonlands	14 73.68%	0 0.00%	5 26.32%
Moderately Rolling Uplands	0 0.00%	14 87.50%	2 12.50%
Gently Dipping Plateaulands	1 4.55%	0 0.00%	21 95.45%

stations (87.5%) were correctly classified. Two Moderately Rolling Upland stations were incorrectly grouped with the Gently Dipping Plateaulands.

Nested ANOVA revealed no significant ($P \leq 0.05$) differences in total station biomass in fifth and sixth order streams among landtype associations. Total station biomass was significantly ($P \geq 0.05$) higher in seventh order streams in the Gently Dipping Plateaulands than in the Crystalline Canyonlands. Mean total station biomass (g/0.305m) and the 95% confidence intervals for the Gently Dipping Plateaulands and the Crystalline Canyonlands were 1.295 ± 0.627 and 0.346 ± 0.076, respectively. Chi-square analysis of richness indicated that differences in the number of taxa per station existed among landtype associations. A chi-square value of 143.81 (probability = 0.001) indicated that richness was significantly ($P \geq 0.05$) different for fifth and sixth order stream stations among landtype associations. Seventh order stream stations also exhibited a significant ($P \geq 0.05$) difference in richness among the Crystalline Canyonlands and the Gently Dipping Plateaulands. The chi-square value for this comparison was 16.57 with a probability of 0.001. No statistical test was available to identify where differences occurred.

DISCUSSION

Physiochemical Characteristics

Differences in physiochemical and biological characteristics within Black Hills streams occurred among landtype associations. The landtype associations studied were geomorphically distinct land units, as defined by Lotspeich and Platts (1982). Distinct changes in stream channel morphometry and fish distribution have been observed among landtype associations, in the Idaho Batholith region (Platts 1979). Platts concluded that geomorphology influenced stream channel gradients, channel substrates, and streambank environments, and thus influenced fish composition and density.

In the present study, stepwise discriminant analysis identified five physiochemical variables which effectively delineated streams occurring among three landtype associations in the Black Hills. The high degree of discrimination suggested that streams within individual landtype associations exhibit integrity. Physiochemical characteristics of streams were similar within individual landtype associations, while differences occurred in streams among landtype associations. Each landtype association was sufficiently different in stream physiochemical composition to permit stratification. In this respect, predictive responses were possible that allowed classification of streams using physiochemical criteria. Invertebrate composition also varied within streams among landtype associations. Streams among landtype associations could be coarsely categorized based on biomass estimates of select taxa. However, invertebrate biomass estimates were not as effective as physiochemical variables in delineating streams among landtype associations.

Differences in streams among landtype associations were related to changes in both stream order and geomorphic structure. The Crystalline Canyonlands were dominated by large seventh and eigth order streams, which exhibited higher sulfate and ortho-phosphate levels than Moderately Rolling Upland and Gently Dipping Plateauland streams. Erosion of sedimentary rock contributes sulfates to streams (Gloterman 1975), therefore sulfates tend to increase downstream (Winget and Mangum 1979). Sulfate concentrations may have been higher because the Crystalline Canyonlands were lowest in the drainage pattern and thereby, represented higher order channels. Erosion of sedimentary rock is also the source of phosphates to streams (Gloterman 1975), and ortho-phosphates exhibited a similar trend as sulfates with higher levels observed in the Crystalline Canyonlands. Conversely, alkalinity was lowest in Crystalline Canyonland streams. The major source of bicarbonates to Black Hills streams is an extensive limestone plateau (Chicago and North Western Railway System 1957), which underlies the Gently Dipping Plateaulands. The limestone nature of the Gently Dipping Plateauland bedrock resulted in higher alkalinity levels in higher elevation streams. The density of instream cover was also different in streams among landtype associations. Instream cover included aquatic vegetation and organic debris (Platts _et_ _al_. 1983), which Bilby and Likens (1980) referred to as organic debris dams. The interaction between streams and terrestrial environments is maximized in headwater streams (Minshall _et_ _al_. 1983) and therefore, headwater streams retain the highest density of organic debris dams (Bilby and Likens 1980). The Gently Dipping Plateauland streams, which are predominantly small headwater streams, contained the highest density of instream cover, whereas the density of instream cover was lowest in Crystalline Canyonland streams.

Thus, differences in the physiochemical characteristics of Black Hills streams, among landtype associations, were associated with both geomorphic orgin and stream order.

Analysis of physiochemical stream characteristics indicated that chemical variables were more important than physical variables in delineating among landtype associations. However, all morphometry data was collected from similar habitats (ie. riffle areas). Therefore, gross differences in stream channel morphometry were not detected among landtype associations. Differences in the frequency of habitat types in streams have been observed among landtype associations (Modde unpublished). Differences in the frequency of habitat types among landtype associations may have influenced the structure and function of invertebrate communities by affecting the quantity and quality of invertebrate habitat.

Differences in the physiochemical characteristics of streams must necessarily impact the distribution of aquatic biota. The predicted community tolerance quotient (PCTQ) proposed by Winget and Mangum (1979) indicated that Black Hills streams differed in invertebrate habitat suitability among landtype associations. Higher PCTQ values, indicative of less suitable invertebrate habitat, were observed in fifth and sixth order Crystalline Canyonland streams, than streams in either the Moderately Rolling Uplands or the Gently Dipping Plateaulands. In seventh order streams, the PCTQ was also higher in the Crystalline Canyonlands than in the Gently Dipping Plateaulands. Higher sulfate and lower alkalinity levels observed in the Crystalline Canyonlands contributed to the higher PCTQ's. Winget and Mangum (1979) reported that sulfate was negatively correlated with invertebrate community diversity, while alkalinity was positively correlated with invertebrate community diversity and standing biomass. Higher PCTQ values indicated that Crystalline Canyonland streams should support invertebrate communities that consist of a greater number of water quality tolerant taxa than found in either Moderately Rolling Upland or Gently Dipping Plateauland streams. The Crystalline Canyonlands consisted mainly of larger streams with less suitable invertebrate habitat, due to lower water quality, associated with geomorphic origin and stream position in the drainage pattern.

Macroinvertebrates

Culp and Davies (1982) stated that longitudinal shifts in macroinvertebrate community structure were related to changes in physical and biological stream characteristics influenced by geomorphology. Macroinvertebrate communities were related to three distinct terrestrial botanical zones which differed in stream valley and channel features. Similarly, surface geology has been reported as affecting the distribution of freshwater mussels in southeastern Michigan (Strayer 1983). In Black Hills streams, macroinvertebrates exhibited distributional patterns that were related to geomorphic structure. The PCTQ values indicated that Crystalline Canyonland streams consisted of less suitable invertebrate habitat than streams of the Moderately Rolling Uplands and Gently Dipping Plateaulands. Cluster analysis indicated that macroinvertebrate community structure was similar within Crystalline Canyonland streams and different than macroinvertebrate communities of the Moderately Rolling Uplands and Gently Dipping Plateaulands. Sixth, seventh, and eighth order Crystalline Canyonland streams clustered together, while seventh order Gently Dipping Plateauland streams were not grouped with this cluster. Therefore, landtype association was more important than stream order in determining invertebrate community structure in Crystalline Canyonland streams.

The quality of invertebrate habitat, as indicated by the PCTQ values, was similar among Moderately Rolling Upland and Gently Dipping Plateauland streams. Cluster analysis indicated that macroinvertebrate community structure was similar among streams within these two landtype associations. Since most aquatic insects have winged stages and high dispersal rates (Hynes 1970), distribution would not represent a limiting factor to colonization of these streams. Where stream environments are similar and organisms have had equal chance for colonization, community structure should be similar (Druer _et_ _al_. 1984). Moderately Rolling Upland and Gently Dipping Plateauland streams were similar in size, physiochemical characteristics and macroinvertebrate community structure. The larger Crystalline Canyonland streams exhibited different physiochemical characteristics and different invertebrate communities. Taxonomic compositional changes further defined similarities within and differences among streams draining different landtype associations. Classifying land units, based on geomorphic structure, represented a viable means of segregating streams.

Hynes (1970) stated that invertebrate standing biomass is variable within and among streams. Standing biomass was also variable within Black Hills streams. No differences in standing biomass were observed in fifth and sixth order streams among landtype associations, however, standing biomass appeared to be lower in Crystalline Canyonland streams. The absence of differences could be the result of the variable nature of biomass or insufficient sample size. Invertebrate standing biomass in seventh order Crystalline Canyonland streams was lower than in seventh order Gently Dipping Plateauland streams. Invertebrate habitat suitability was lower in the Crystalline Canyonlands and this may have impacted the standing biomass. The higher density of instream cover in Gently Dipping Plateauland streams may also have affected standing biomass by providing a greater diversity of invertebrate habitat. Differences in both invertebrate composition and standing biomass varied in associations with changes in physiochemical characteristics among landtype associations.

Differences in invertebrate richness also occurred among landtype associations. Observed differences indicated that patterns of macroinvertebrate community structure varied among landtype associations. Invertebrate richness is expected to decrease with natural or man induced environmental stress (Platts _et al_. 1983). Winget and Mangum (1979) reported that invertebrate richness varies with changes in water quality among streams. Invertebrate richness was different in fifth and sixth order streams among landtype associations and in seventh order streams among the Crystalline Canyonlands and the Gently Dipping Plateaulands. Although no statistical test was available to determine where differences occurred, these changes in richness could be the result of differences in macroinvertebrate community structure among landtype associations.

Multivariate analytical techniques were effective in separating landtype associations on the basis of physiochemical variables. Streams among landtype associations exhibited differences in physiochemical characteristics, invertebrate community structure, standing biomass, and richness. Such differences supported the concept of integrity of streams within landtype associations.

Stream order and geomorphic structure within landtype associations acted synergistically in structuring stream environments in the Black Hills. Because landforms are sculptured by flowing water, streams are inseparably interrelated with their drainage basins (Cummins 1974, Hynes 1975). Culp and Davies (1982) suggested that heirarchial land classification would aid in the interpretation of river zonation studies. The heirarchial classification system proposed by Lotspeich and Platts (1982) integrates streams into the land classification process. The heirarchial level of classification, landtype association, is an appropriate level for detecting differences among streams.

Geoclimatic factors develop landscapes to provide the physical template for stream ecosystem development. The interaction of soils, vegetation, and biotic processes, which contribute to the development of stream environments, are accounted for by categorizing similar land units together. Macroinvertebrate community structure represents a response to the biotic and abiotic stream ecosystem. Heirarchial land classification can aid in the understanding and interpretation of macroinvertebrate distribution and community structure.

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APPENDIX

Table A. Macroinvertebrate sampling site locations for Black Hills stream study. Data was collected during August (7-15), 1985 and August (1-4), 1986.

Site	Location
CRYSTALLINE CANYONLANDS	
1/2	SE1/4, SW1/4, NW1/4, Sec 14; T1N; R6E
3/4	NE1/4, NW1/4, NW1/4, Sec 9; T1N; R6E
7/8	SW1/4, SW1/4, NE1/4, Sec 34; T2N; R4E
9/10	NE1/4, NW1/4, NE1/4, Sec 7; T1N; R4E
11/12	SW1/4, SW1/4, NW1/4, Sec 19; T2N; R4E
13/14	NW1/4, SW1/4, NW1/4, Sec 22; T1N; R6E
65/66	NE1/4, SE1/4, SW1/4, Sec 9; T1N; R6E
69/70	NW1/4, NE1/4, SE1/4, Sec 34; T2N; R4E
73/74	SE1/4, NE1/4, NW1/4, Sec 9; T1N; R5E
MODERATELY ROLLING UPLANDS	
27/28	NW1/4, NE1/4, NE1/4, Sec 18; T3N; R4E
31/32	NE1/4, NW1/4, SW1/4, Sec 30; T4N; R4E
33/34	SE1/4, SW1/4, SW1/4, Sec 9; T4N; R4E
35/36	NW1/4, NE1/4, SE1/4, Sec 19; T3N; R3E
37/38	NW1/4, NE1/4, NE1/4, Sec 29; T3N; R3E
95/96	SW1/4, NW1/4, SW1/4, Sec 32; T3N; R3E
101/102	SE1/4, NW1/4, NW1/4, Sec 12; T1S; R2E
103/104	NW1/4, SW1/4, NW1/4, Sec 27; T4N; R4E
GENTLY DIPPING PLATEAULANDS	
15/16	NE1/4, SE1/4, SW1/4, Sec 31; T2N; R2E
17/18	SE1/4, NW1/4, NE1/4, Sec 10; T2N; R2E
19/20	NE1/4, SE1/4, SW1/4, Sec 21; T4N; R1E
21/22	SW1/4, NW1/4, SW1/4, Sec 24; T5N; R1E
23/24	SE1/4, SE1/4, NE1/4, Sec 8; T2N; R1E
25/26	SE1/4, NW1/4, SW1/4, Sec 1; T2N; R5E
83/84	NW1/4, SE1/4, SW1/4, Sec 11; T2N; R2E
85/86	NW1/4, NE1/4, NE1/4, Sec 7; T2N; R1E
87/88	NW1/4, NW1/4, NE1/4, Sec 12; T2N; R5E
89/90	SE1/4, NE1/4, NE1/4, Sec 24; T3N; R2E
91/92	NW1/4, NW1/4, SW1/4, Sec 15; T2N; R2E

APPENDIX

Table B. Chemical data collected from streams in the Black Hills of South Dakota. Data collected during August 7-15, 1984 and August 1-4, 1985.

Site	Stream	Temp °C	pH	Turb NTU	Alk mg/l	Cond umhos/cm	PO_4 mg/l	NO_3 mg/l	SO_4 mg/l
CRYSTALLINE CANYONLANDS									
1	Rapid	14	8.2	1	160	290	13	<0.10	38.0
2	Rapid	10	8.0	2	-	178	10	<0.10	37.0
3	Rapid	9	8.4	0	170	260	10	<0.10	35.0
4	Rapid	9	8.7	1	150	270	12	0.12	36.0
7	Rapid	18	8.3	2	160	175	35	<0.10	28.0
8	Rapid	17	8.4	2	160	175	25	<0.10	28.0
9	Castle	14	8.4	5	200	340	<10	0.22	35.0
10	Castle	15	8.4	5	190	340	<10	0.13	37.0
11	Rapid	18	8.4	3	205	350	<10	0.10	26.0
12	Rapid	18	8.4	3	200	340	<10	<0.10	27.0
13	Prairie	19	7.9	0	130	300	12	<0.10	36.0
14	Prairie	19	8.0	0	110	305	20	<0.10	36.0
65	Rapid	9	8.4	1	140	252	13	<0.10	38.0
66	Rapid	10	8.6	0	140	250	10	<0.10	37.0
69	Rapid	19	8.6	1	190	335	<10	<0.10	36.0
70	Rapid	22	8.3	1	184	365	<10	<0.10	34.0
73	Castle	14	8.4	1	230	255	12	<0.10	10.0
74	Castle	15	8.4	1	232	255	20	<0.10	10.0
GENTLY DIPPING PLATEAULANDS									
15	Castle	11	8.8	1	240	328	14	<0.10	2.5
16	Castle	11	9.0	8	200	320	20	<0.10	2.5
17	S. Fork Rapid	9	8.5	1	200	340	15	<0.10	2.5
18	S. Fork Rapid	10	8.5	1	250	335	14	<0.10	1.5
19	Little Spearfish	12	8.3	0	220	320	<10	0.12	1.5
20	Little Spearfish	13	8.1	0	230	310	<10	0.12	1.5
21	Iron	26	8.7	2	170	252	18	<0.10	1.5
22	Iron	26	8.8	2	180	262	20	<0.10	1.5
23	Cold Springs	13	8.4	2	250	325	22	<0.10	1.5
24	Cold Springs	13	8.3	2	250	330	19	<0.10	1.0

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Table B. continued.

25	Box Elder	18	8.3	0	145	250	28	<0.10	8.5
26	Box Elder	18	8.5	0	150	245	29	<0.10	9.2
83	Rhoads Fork	19	8.3	0	250	320	<10	<0.10	3.0
84	Rhoads Fork	19	8.4	0	223	320	10	<0.10	2.0
85	Cold Springs	10	8.2	0	249	280	<10	0.19	<1.0
86	Cold Springs	10	8.4	1	256	290	<10	0.20	<1.0
87	Box Elder	20	8.0	1	197	310	<10	<0.10	15.0
88	Box Elder	19	7.9	1	192	320	<10	<0.10	14.0
89	Buskala	13	8.0	0	255	290	<10	0.32	2.0
90	Buskala	10	7.7	1	255	255	10	0.11	1.0
91	Rhoads Fork	14	8.2	0	240	310	10	<0.10	2.0
92	Rhoads Fork	17	8.5	1	235	310	<10	<0.10	2.0
MODERATELY ROLLING UPLANDS									
27	N. Box Elder	17	8.1	11	160	245	-	-	-
28	N. Box Elder	17	8.1	9	160	245	-	-	-
31	Elk	16	8.5	10	210	320	30	<0.10	1.5
32	Elk	18	8.5	10	210	320	30	<0.10	1.5
33	Bear Butte	23	8.6	3	90	200	18	<0.10	13.0
34	Bear Butte	22	8.4	3	90	198	24	<0.10	13.0
35	Buskala	17	8.3	3	210	350	35	<0.10	<1.0
36	Buskala	17	8.3	3	220	352	30	<0.10	<1.0
37	Buskala	17	8.5	3	180	241	30	<0.10	<1.0
38	Buskala	17	8.4	2	180	242	24	<0.10	<1.0
95	Swede Gulch	17	8.1	4	150	168	<10	<0.10	4.0
96	Swede Gulch	16	8.1	4	140	160	<10	<0.10	5.0
101	Heely	20	8.4	8	283	382	25	0.12	10.0
102	Heely	22	8.4	6	277	359	<10	0.16	11.0
103	Elk	18	9.0	2	158	280	30	0.34	19.0
104	Elk	18	8.7	2	175	270	30	<0.10	19.0

APPENDIX

Table C. Composite list of macroinvertebrate taxa collected from streams in the Black Hills of South Dakota. Invertebrates collected during August 7-15, 1984 and August 1-4, 1985. Sampling was stratified by landtype association. Values represent the % frequency of occurance of each taxa in each landtype association.

	LANDTYPE ASSOCIATIONS		
Taxa	CC	MRU	GDP
Phylum Aschelminthes			
Class Nematoda	0.00	43.75	31.82
Phylum Mollusca			
Class Gastropoda	21.05	56.25	18.18
Class Pelecypoda	47.37	68.75	77.27
Phylum Annelida			
Class Hirudinea	0.00	25.00	22.73
Class Oligachaeta	72.68	100.00	100.00
Phylum Platyhelminthes			
Class Turbellaria	0.00	0.00	13.64
Phylum Arthropoda			
Class Arachnida			
Suborder Hydracarina	94.74	100.00	90.91
Class Crustacea			
Order Amphipoda			
Family Gammaridae	5.26	12.50	77.27
Class Insecta			
Order Collembola			
Family Entomobryidae	21.05	43.75	4.55
Order Lepidoptera			
Family Pyralidae			
Petrophila	0.00	37.50	18.18
Order Ephemeroptera			
Family Baetidae			
Baetis	100.00	100.00	100.00
Family Heptageniidae			
Epeorus	26.32	0.00	9.09
Family Leptophlebiidae			
Paraleptophlebia	68.42	0.00	27.27
Leptophlebia	0.00	37.50	13.64
Family Tricorythidae			
Tricorythodes	26.32	56.25	27.27

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Table C. continued.

Family Ephemerellidae			
Dannella	21.05	25.00	0.00
Ephemerella	5.26	0.00	4.55
Order Odonata			
Family Gomphidae			
Ophiogomphus	31.58	43.75	4.55
Family Coenagroinidae			
Argia	0.00	12.50	9.09
Order Hemiptera			
Family Gerridae	0.00	0.00	6.25
Order Plecoptera			
Family Nuemouridae			
Malenka	100.00	75.00	72.73
Family Perlodidae			
Isoperla	42.11	0.00	0.00
Family Chloroperlidae	100.00	81.25	81.25
Family Perlidae			
Acronueria	10.53	0.00	4.55
Classenia	0.00	6.25	0.00
Order Trichoptera			
Family Rhyacophilidae			
Rhyacophila	31.58	18.75	54.55
Family Glossosomatidae			
Glossosoma	68.42	56.25	9.09
Family Philopotamidae			
Dolophilodes	0.00	0.00	22.73
Wormaldia	10.53	6.25	0.00
Family Polycentropodidae			
Polycentropus	0.00	6.25	0.00
Cernotina	10.53	0.00	0.00
Family Hydropsycidae	47.37	93.75	36.36
Hydropsyche	78.95	37.50	22.73
Cheumatopsyche	15.79	31.25	13.64
Family Hydroptilidae	47.43	18.75	27.27
Luecotricha	0.00	25.00	18.18
Family Limnephilidae	0.00	25.00	22.73
Hesperophylax	0.00	18.75	22.73
Family Leptoceridae			
Oecetis	0.00	25.00	18.18
Nectopsyche	0.00	18.75	0.00
Family Lepidostomidae			
Lepidostoma	15.79	0.00	31.82
Family Brachycentridae			
Brachycentrus	63.16	62.50	13.64
Micrasema	73.68	43.75	68.18

APPENDIX

Table C. continued.

Family Helicopsychidae			
Helicopsyche	5.26	68.75	22.73
Family Odontoceridae	0.00	18.75	0.00
Order Coleoptera			
Family Dytiscidae	10.53	18.75	4.55
Family Hydrophilidae	5.26	0.00	0.00
Family Elmidae	100.00	100.00	95.45
Dubiraphia	0.00	6.25	18.18
Zaitzevia *	21.05	37.50	4.55
Optioservus *	78.95	81.25	22.73
Family Psephenidae	0.00	6.25	0.00
Family Curculoinidae	5.26	0.00	4.55
Order Diptera			
Family Tipulidae			
Antocha	63.16	56.25	59.09
Dicranota	0.00	31.25	68.18
Hexatoma	57.89	31.25	27.27
Tipula	10.53	6.25	4.55
Ormosia	5.26	0.00	4.55
Erioptera	5.26	0.00	0.00
Limonia	0.00	0.00	9.09
Family Psychodida			
Pericoma	0.00	6.25	45.45
Family Dixidae			
Dixa	10.53	43.75	36.36
Family Simuliidae	94.74	50.00	86.36
Family Chironomidae	100.00	100.00	100.00
Family Ceratopogonidae			
Probezzia	42.11	75.00	72.73
Family Straitomyidae			
Euparyphus	0.00	0.00	27.27
Family Tabanidae	0.00	6.25	0.00
Family Rhagonidae			
Atherix	21.05	31.25	0.00
Family Empididae	52.63	6.25	18.36
Family Ptychoptera	0.00	12.50	27.27

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* Only Adults identified to generic level.