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Benthic Insect Community Structure in Cumberland Mountain Streams Twenty-five Years After Coal Strip Mining

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To the Graduate Council:

I am submitting herewith a thesis written by Elizabeth B. Williams entitled "Benthic Insect Community Structure in Cumberland Mountain Streams Twenty-five Years After Coal Strip Mining." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of , with a major in Ecology and Evolutionary Biology.

Gerald R. Vaughan, Major Professor

We have read this thesis and recommend its acceptance:

Dewey Bunting, Clifford Amundsen, David Etnier

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Elizabeth B. Williams entitled "Benthic Insect Community Structure in Cumberland Mountain Streams Twenty-five Years After Coal Strip Mining." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology.

Gerald L. Vaughan, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

BENTHIC INSECT COMMUNITY STRUCTURE IN CUMBERLAND MOUNTAIN STREAMS TWENTY-FIVE YEARS AFTER COAL STRIP MINING

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Elizabeth B. Williams

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ABSTRACT

In order to evaluate long-term impacts of coal strip mining on small stream benthic fauna in the Cumberland Mountains of east Tennessee, four streams, two in watersheds mined twenty-five years ago and two undisturbed, were sampled monthly for six months, January through June, 1979. Benthos was sampled by collecting eight Surber samples, each two $ft.^2$ in area, from similar riffles in each stream. At the collection sites pH, dissolved O_2, and velocity were measured. Water samples were analyzed in the laboratory for alkalinity and hardness (measured as mg/l $CaCO_3$) and dissolved Fe and SO_4 (mg/l) concentrations.

Benthic data analysis was both quantitative and qualitative. Quantitative evaluation included analysis of variance of density of individuals/unit area, numbers of taxa, and species diversity (Shannon-Weaver index). Qualitative analysis included evaluation of the distribution and abundance of various taxa among the streams and the taxonomic similarity (computed by the modified Sorenson similarity coefficient).

Results indicated that the undisturbed streams had significantly greater densities of individuals and numbers of taxa, but not species diversity. Qualitatively, the undisturbed streams have more taxa with many individuals than do the streams affected by strip mining. The similarity index indicated the undisturbed streams to be most similar with the mining-affected streams being the next most similar. Although this study does not prove that strip mining caused the observed decreases in numbers of taxa and density of individuals per unit area,

it suggests that such extensive damage to small watersheds may reduce benthic productivity for as long as twenty-five years, and indicates further research may be necessary to determine factors causing a depressed fauna for so long.

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INTRODUCTION

Since 1973, an increasing emphasis on utilization of domestic coal reserves has resulted from the rising expense of imported oil and dwindling domestic oil supplies. As a consequence, related environmental impacts are of growing importance. While coal combustion byproducts may contribute to air pollution, the mining of coal often has serious impact on water quality. In eastern coal fields, where rainfall is plentiful, local water quality is often degraded by the soil erosion associated with surface mining and the leaching of acidic materials from deep and auger mines (Boccardy and Spaulding, 1968; Curtis, 1977).

Although acid drainage is a common problem, in east Tennessee and geologically similar areas, mine drainage may be alkaline (Minear and Tschantz, 1976; Curtis, 1972a). It is only relatively recently that mining effects have been studied independently of the effect of acid drainage. In Kentucky, Curtis (1972a) has reported surface mining effects in an area with alkaline drainage. The New River area of Tennessee also may have alkaline drainage resulting from surface mine runoff. Hydrologic, chemical and biological studies of mining affected streams in this area have been conducted continuously since the initiation in 1975 of a Department of Energy (DOE) project, ENVIRONMENTAL ASPECTS OF COAL PRODUCTION IN THE APPALACHIAN REGION, by the Departments of Geology, Civil Engineering, and Zoology at The University of Tennessee, Knoxville.

From this investigation of the effects of strip mining on the New River system, several problems have been defined. Primary chemical changes in stream water quality are increases in alkalinity, hardness, and Fe, SO_4, and Mn concentrations. There may also be a slight increase in pH (Minear and Tschantz, 1976). Changes in chemistry are accompanied by increases in suspended solids concentrations (Minear et al., 1976, 1977, 1978, 1979, 1980) and increased peak and low flow (Tung, 1975; Bohm, et al., 1974). In the small streams affected by these changes, there are decreases in the numbers and changes in the composition of the benthic fauna depending on the degree of disturbance (Tolbert, 1978; Talak, 1977; Vaughan, et al., 1978). Fish also are affected, generally with decreases in population sizes and diversity (Vaughan, 1978).

Study of the chronology of recovery (Talak, 1977; Vaughan, et al., 1978) indicates that even after twenty years streams affected by mining may have a community composition different from that of unaffected streams. The present research takes the recovery studies as a starting point and examines two streams affected by mining twenty-five years ago to determine how their benthic invertebrate communities differ from those of two control streams over a six month period. This study is part of the continuing DOE project and was supported under contract number EY-76-S-05-4946.

CHAPTER I

LITERATURE REVIEW

During the past decade there has been a dramatic shift in the focus of our national interest in energy from petroleum to coal. In 1973 the Arab oil embargo pressed the Federal Government toward a policy of independence from foreign energy sources (Where We Agree, 1979). That year the Nixon Administration responded with Project Independence, which projected national energy independence by 1980. Two of the six major tasks of the project focused on (1) expanding the use and production of coal, and (2) reducing the adverse environmental effects associated with energy production and consumption (Tung, 1975). Emphasis on the utilization of coal was reaffirmed in 1975 by the Energy Conservation and Development Act (P.L. 94-163), with Section 2 setting national policy to "increase the supply of fossil fuels in the United States . . . and to reduce the demand for petroleum products and natural gas through programs designed to provide greater availability and use of the Nation's abundant coal resources . . ." (Morgan, 1976). For a review of legislation pertaining to the use of coal, see the Office of Technology Assessment Report (1979).

Presently coal is the fuel of choice to replace imported fossil fuels because it is abundant in the United States, and unlike nuclear energy, the technology for production and utilization is well developed. A 1979 report to the House Committee on Science and

Technology by the Office of Technology Assessment (OTA) states that coal production could triple by the year 2000 without substantial regulatory relaxations or major technological innovations. The same report indicates that the United States has coal deposits which contain enough energy to supply present energy demand for 5,000 years. The presently estimated recoverable reserves, different from deposits which include coal not presently mineable, equal 283 billion tons of coal and would permit the use of coal as a major energy source through the twenty-first century, with present technology. Supposing continuing advances in technology and economic demand, seams which are not now profitable might add to future production. In contrast, the OTA report indicates that known reserves of crude oil would last for twenty years at the same rate of depletion.

Our projected coal demand is directly related to our total energy need. Various factors will affect future use, including population size, economic activity, efficiency of energy use, and availability of alternate energy sources. For the year 2000 most predictions of total energy demand fall between 100 and 150 quadrillion BTU's (Quads). Usage in 1975 was 73.1 Quads. Although BTU content varies in different kinds of coal, 75 Quads equal approximately 3.75 billion tons (Office of Technology Assessment, 1979). The actual fraction of coal in the future energy budget is undetermined, with tonnage estimates varying from a low of .7 billion to a high of 2.3 billion tons for the year 2000 (Rotty and Weinberg, 1976).

Future coal demand will be directly related to electricity production, as utility companies presently account for about 70% of total coal usage, and current legislation encourages increasing utilization of coal by power plants (Morgan, 1976; Office of Technology Assessment, 1979). Already there is an increasing use of coal by utilities, rising from 44% of production in 1970 to 47% in 1977. For the same period, tonnage used has increased from 319 to 480 million tons (Energy Research and Development Administration, 1977).

As coal production and combustion rise, there will be the potential for increased environmental stress, both from mining activities and combustion byproducts. Some effects are immediately obvious, while others, like increasing concentrations of CO_2 in the atmosphere, may take years before they are recognized and even longer before the consequences are known. This external, environmental cost of coal usage has received increasing attention as shown by national legislation attempting to mitigate adverse environmental effects of production and combustion.

In the Eastern United States, coal fields are generally located in areas of moderate relief and plentiful rainfall; consequently, water pollution resulting from soil erosion and chemical changes has long been a problem (Boccardy and Spaulding, 1968; Curtis, 1977). The present research is directed toward assessing the long-term effects of coal surface mining on small stream benthic fauna in the Cumberland Mountain coal region of east Tennessee.

Both deep and surface mining of coal are practiced in the Cumberland Mountain area, depending on the characteristics of the coal seam being mined. While the surface disturbance associated with deep mines results in some erosion and stream siltation, the acid drainage resulting from groundwater leaching of sulfide materials and subsequent oxidation to H_2SO_4 can have a severe impact on receiving waters.

Acid mine drainage, often from abandoned deep mines, is a widespread problem in eastern coal fields, and its effects on stream biota have been reported by several authors. Effects on aquatic insects have been investigated by Herricks and Cairns (1974), Cairns, et al. (1971), Dills and Rogers (1974), and Roback and Richardson (1969). Although there is some acid drainage in the Cumberlands, the carbonate rocks present often lead to alkaline drainage, particularly in association with surface mining (Minear and Tschantz, 1976).

In these mountainous areas, contour surface mining is accomplished by mechanically removing the rock (overburden) overlying the coal seam from a narrow ledge around the side of the mountain. Permanent changes in the hydrology of strip mined watersheds result from deforestation of the watershed, rearrangement of acres of soil, fracturing of rock previously inaccessible to weathering, and changes in surface and groundwater flow patterns. Changes in water quality following strip mining have been investigated in east Tennessee and similar areas and can generally be categorized into three areas of concern: (1) physical and chemical qualities of the water (sediment load and dissolved components) (Boccardy and Spaulding, 1968; Minear and Tschantz, 1976; Collier, et al., 1964, 1970; Rose, 1975; Curtis, 1977), (2) flow characteristics (storm response and dry weather flow) (Tung, 1975; Curtis, 1972b; Collier, et al., 1964, 1970; Bohm, et al., 1974), and (3) the biology (ability to support fish and invertebrate populations) (Talak, 1977; Vaughan, 1978; Collier, 1964, 1970; Tolbert, 1978; Boccardy and Spaulding, 1968; Vaughan, et al., 1978).

These studies report data from mining situations where there is no effective buffer zone between the mines and the streams due either to small watershed size or occurrence of mining before such regulating legislation. They will be examined in more detail in the following sections.

Physical and Chemical Qualities of the Water

The processes of weathering, erosion, and sediment transport are active in all watersheds, but these processes are typically very slow in a forested, undisturbed watershed where the soil is protected from erosion by vegetation. Comparative hydrologic studies of mining-affected and undisturbed watersheds in the New River system of east Tennessee indicate 25 mg/l suspended solids (SS) as typical of streams in undisturbed watersheds (Minear and Tschantz, 1976). Another study of mining related hydrologic changes was conducted by Collier, et al. (1964, 1977) in the Beaver Creek Basin in McCreary County, Kentucky, an area geologically similar to the Cumberland Mountains in Tennessee. There it was found that a stream draining an undisturbed watershed had a suspended solids concentration of 14 to 17 ppm (= mg/l), a value similar to that for the New River study.

Once surface mining begins, there may be tremendous increases in sediment transport by streams in affected watersheds as evidenced by increased turbidity, suspended solids, and bed load. The Beaver Creek basin study mentioned above illustrates this, as the Cane Creek watershed, disturbed by intermittent strip mining from 1956-1959, affecting 10.4% of the total watershed area, produced a sediment yield varying from 588 tons/mile^2 of watershed in 1956 to 1,930 tons/mile^2 in 1958. This is 69 times the 27.9 tons/mile^2 reported for the adjacent, undisturbed watershed.

In addition to quantities of material made available for erosion by surface disturbance, fractured rock is exposed to chemical leaching action by water percolating through spoil banks, and the chemistry of the runoff and ground water may be changed. In the Tennessee and Kentucky studies mentioned above, undisturbed and mining-affected streams were contrasted, and increases in alkalinity, pH, SO_4, Ca, Mg, Fe, and Mn concentrations were found to be a function of degree and duration of disturbance.

In the New River watershed in particular, pH and alkalinity in undisturbed streams were found to be generally low, with pH between 6 and 7 and alkalinity (measured as mg/l $CaCO_3$) consistently less than 10 mg/l. In the mined watersheds, a rise in alkalinity was observed, varying among study streams with degree of mining, but fluctuating from 10 mg/l to more than 30 mg/l. Similarly, pH showed an increase, varying between 6.5 and 7.5 in affected streams (Minear and Tschantz, 1976).

Curtis (1972a) found Ca and Mg concentrations in streams to increase almost immediately with the onset of mining in the watersheds. Values in undisturbed streams were generally low, less than 10 mg/l for both ions, but increasing to more than 15 mg/l Mg and 20 mg/l Ca following the initiation of mining in a watershed. The New River study showed the same quick increase in Ca and Mg concentrations in streams draining mining-affected watersheds.

In addition to Ca and Mg, SO_4 concentrations increase in direct relation to the extent and duration of mining. There is, however, a lag between initiation of mining and a rise in SO_4. In Kentucky, Curtis found SO_4 to increase from a maximum of 84 mg/l in an undisturbed stream to a maximum of 300 mg/l in a stream draining a mined area. Similar values are indicated by Minear and Tschantz (1976) for the New River area, and both studies indicate elevations in SO_4 continuing long after the cessation of mining. Further evidence of this can be seen in the Duncan Creek watershed, Campbell County, Tennessee. This area was mined twenty-five years ago and stream sulfate values still exceed 100 mg/l at times (Vaughan, unpublished data).

Fe and Mn values also were found to increase following disturbance, with concentrations in the Tennessee streams frequently above drinking water standards for Fe (Minear and Tschantz, 1976).

Flow Characteristics of Streams

Changes in the chemical constituents of streams accompany changes in flow patterns. Often there is increased peak flow during wet weather, and increased dry weather flow in streams draining mining-disturbed watersheds. The steepness of topography combined with the shallow, rocky soils in the Cumberland Mountain area results in most precipitation being lost as surface runoff. Consequently many of the smaller streams in undisturbed watersheds are dry during the late summer and early fall when there is little rain (Tung, 1975; Gairola, 1947; Curtis, 1977). The extensive spoil banks resulting from strip mining have a large water storage capacity, and seepage during dry weather results in as much as a ten-fold increase in dry weather stream flow (Bohm, et al., 1974).

This increase in the watershed retention ability is somewhat paradoxical in its effect on wet weather flow. Tung (1975) studied changes in the New River system discharge patterns over a thirty year period (1950-1970) in response to the increasing mining during this period. His study indicated that an increase in peak flow during wet weather occurred in the 1950 period when strip mining was in the early stages, and most watersheds had only one mining cut. During the 1960 period when strip mining was more extensive, often with several cuts in a watershed, retention was increased through storage in spoil banks and ponding on benches. Wet weather peak flow decreased during this period. The present condition, 1970's, shows further increase in peak flow, or decreased storm carrying capacity, as the benches and spoil banks have become saturated and water is channeled directly into the streams. Additional evidence for an increase in peak flows following surface mining can be found in the studies by Collier, et al. (1964, 1970) and Curtis (1972b) in Kentucky.

Biology of Streams

The following discussion on the effects of mining on stream biota will focus primarily on benthic macroinvertebrates as they are frequently used in water quality assessment (Hynes, 1970; Hilsenhoff, 1977; Cairns, et al., 1971). Benthic insects are of particular value because they are relatively immobile and provide a record of continuous changes in water quality which might not be detected by periodic chemical testing of water alone.

In the east Tennessee area being studied, the main effects of strip mining on water quality are (1) increased sedimentation, (2) changes in water chemistry, (3) increased peak flow, and (4) increased dry weather flow. No reports of the effects of dry weather flow were found in the literature, but there are indications that some affected streams may now support populations of fish (Semotilus atromaculatus) through summer and fall when previously there was insufficient water (Vaughan, unpublished data). Generally, the other factors affect the biota of streams draining strip mined watersheds by reducing populations of certain taxa and eliminating others, depending on the extent and duration of disturbance and the sensitivity of the organisms.

Sedimentation and increased peak flow, in particular, have been determined as major strip mine related factors affecting benthic communities in Cumberland Mountain streams (Tolbert, 1978). The settling of suspended solids from the water column affects benthos through a smothering effect on habitats, individuals, and food sources. A study in Kentucky by Branson and Batch (1972) provides a worst case example of the effects of silt deposits. In Leatherwood Creek, which accumulated two to six inches of clay after the onset of mining in the watershed, they found salamanders "entombed under rocks." The mayfly and crayfish populations were found to have decreased by 90% following mining. Other field studies of mining effects on stream biota document the decrease of diversity and density of benthic faunas (Carter, 1964; Hensley, 1970; Talak, 1977; Tolbert, 1978; Vaughan, et al., 1978; Herricks and Cairns, 1974). Aside from the total smothering of organisms, sediment deposition may alter the composition of benthic fauna simply by reducing the available habitat and increasing the instability of the substrate (Chutter, 1969). Barton (1977) found a change in the composition of the benthic fauna affected by highway construction. Although the numbers of individuals and species remained relatively constant, there was an increase in species which are quick to recolonize and are common in drift samples.

As sediment settles from the water column, it not only affects the biota present at that time, but also it may restrict future recolonization by insects. Leudtke and Brusven (1976) tested several species of aquatic insects and found that few species other than a heavy cased caddisfly (Trichoptera) would consistently travel upstream on sanded areas even at low water velocities. They speculated that unstable substrate was responsible. Although the streams in the Cumberland Mountains are typically affected by silt, rather than sand, the general effect of an unstable substrate may be the same.

Certain fish also may be adversely affected by siltation as the populations of benthic organisms that bottom feeders utilize are reduced, while others (the creek chub, *Semotilis atromaculatis*, in particular) are more resistant (Branson and Batch, 1972) and may even grow larger in affected streams, possibly as a consequence of reduced competition (Vaughan, Tolbert, and Stair, unpublished data).

The erosion silt which remains suspended can also have negative effects. Increased turbidity and reduced clarity result in a decrease in light penetration and potential primary production. Although small wooded streams receive much of their energy input from external (allochthanous) sources such as leaf fall, there is also internal (autochthanous) primary production by periphyton and macrophytes (Minshall, 1967; Cummins, 1973). The reduction of light penetration and the settling of sediment on these plants may eliminate them and thus a source of food for grazers in the animal community (Hynes, 1970).

Increased peak wet weather flow following removal of ground cover in mined watersheds works with deposited sediment to scour stream beds, washing out loose substrate and crushing benthos by the abrading action of moving rocks and gravel (Moffet, 1936; Hynes, 1970). Flooding also washes out the plant litter which, to a large degree, forms the base of the trophic structure in small wooded streams (Minshall, 1967; Cummins, 1973). Thus, mining affects streams through excessive smothering of the benthic habitat by settling of sediment during low flow periods and the scouring of stream beds during high flow.

While low pH is not generally associated with strip mining in the Cumberland Mountains, other changes in water chemistry could potentially affect benthos. Although no toxicity studies of SO_4, Ca, and Mg were found in the literature, these substances may have an effect on distribution. Increases in alkalinity and hardness (measured as $CaCO_3$) following strip mining may not decrease overall density of individuals/unit area, but there is some evidence that community composition may be altered. Streams which are quite low in these values, less than 30 mg/l $CaCO_3$, have been shown in one study (Neel, 1973) to have fewer aquatic plants and a different fauna, in particular fewer molluscs, than streams with concentrations greater than 50 mg/l. Neel found some differences in the composition of the benthic insect communities also, with a few taxa being shared by all streams, while many others were specific to one or the other category. Hynes (1970) discusses the faunal characteristics of hard and soft waters and concludes either may have a rich fauna depending on local conditions.

Effects of SO_4 are unclear. Although SO_4 values may be reported in conjunction with benthic studies, i.e., the EPA manuals on Environmental Tolerances of Aquatic Insects (Surdick and Gaufin, 1978; Beck, 1977; Hubbard and Peters, 1978; Harris and Lawrence, 1978), there are no indications of how invertebrates are affected by various concentrations.

The major detrimental influences on the benthic insect communities in non-acid mining situations in the Cumberland Mountains have been shown to be habitat alteration and destruction through the actions of sediment deposition, and streambed scouring. Any disturbance such as road building or logging which might facilitate watershed erosion may have similar effects on stream biota. Once disturbance stops, recovery will depend on (1) severity and duration of stress, (2) recolonization of the damaged area by aquatic organisms, and (3) residual effects of stress or associated materials (Herricks and Cairns, 1974). Additional factors which affect the structure of the returning community are water level and season of year (Larimore, et al., 1959).

Downstream drift is of primary importance in the recolonization of damaged streams by invertebrates. Although estimates of the contribution of drift in recolonization vary from 82% (Townsend and Hildrew, 1976) to 41.4% (Williams and Hynes, 1976) of the total number recolonizing, it is considered to be the major mechanism and fastest means by which repopulation occurs. Additional means of recolonization by stream fauna are: (1) upstream migration, (2) aerial sources, including oviposition, and (3) migration from within the substrate (Williams and Hynes, 1976). In situations where stream damage is not total, residual and resistant populations may reproduce and contribute to repopulation.

When stress is short term and conditions quickly return to pre-disturbance levels, recovery may be rapid if there are healthy populations of organisms nearby to repopulate the disturbed area. Herricks and Cairns (1974) experimentally stressed a natural stream by artificially creating low pH (4.0) in a section for 15 minutes. After the acid treatment, diversity and density decreased from 3.91 for diversity and 74 organisms/$ft.^2$ to 2.79 diversity and 43 organisms/$ft.^2$. Diversity was calculated using the method described by Wilhm and Dorris (1968). Within 19 to 28 days the stream had returned to pre-disturbance levels of density and diversity. Another study of repopulation to two invertebrates which dominated the benthic fauna of a stream indicates recovery of small areas can be quite rapid--within one to four days (Waters, 1964). However, in the event of residual toxicity, or persistent habitat change, the stream community may be much slower to recover. Dimond (1967) studied patterns of drift and recolonization of streams sprayed by DDT, and observed that recovery of numbers of invertebrates occurred within a year due to increases in individuals with short life cycles, but that taxa with longer life cycles took two to three years to return to normal levels. An even longer recovery period has been indicated by Talak (1977) in his study of twenty-three Cumberland Mountain streams variously affected by surface mining. His research and that of others in the same area indicates that numbers of individuals and taxa may be depressed for as long as ten years or more, and that community structure may be different even after twenty years has elapsed (Vaughan, et al., 1978).

The present study takes the findings by Talak and others as a starting point and examines the benthic community structure of two streams which are undisturbed by mining, and two streams affected by strip mining twenty-five years ago. The time frame of the study is extended beyond the two months in the previous study to six months, from January through June of 1979. The present study was undertaken because the above findings suggested a continuing effect of the coal mining disturbance lingering after visible effects in the streams were gone. Further investigation can contribute valuable information about stream community response to strip mining disturbance.

CHAPTER II

STUDY SITE

The four study streams are located in the Cumberland Mountains of east Tennessee, a physiographic region of the Appalachian Plateaus Province (Thornbury, 1965). Historically, the Appalachian region, including Kentucky, West Virginia, Virginia, Pennsylvania, and Tennessee accounts for 60% or more of the total domestic production of coal since mining began in the U.S. (Office of Technology Assessment, 1979). Since the 1940's, there has been a rapid increase in the extent of surface mining with the availability of larger machinery. The Tennessee counties most heavily affected are Anderson, Campbell, Scott, and Morgan with over 33,890 acres, or 65% of the total acreage disturbed in Tennessee as of 1974. The study streams are in Scott, Morgan, and Campbell Counties which together account for 26,785 (51%) of the total acreage disturbed by surface mining in Tennessee (Leamon and Maher, 1974).

Lowe Branch and Indian Creek, draining unmined watersheds, are in Scott County and are tributaries of the New River, part of the Cumberland system. The two disturbed streams are in the Tennessee River system. Duncan Creek, in Campbell County, is a tributary of Cove Creek, and Dry Branch, in Morgan County, is a tributary of the Emory River. Figure 1 shows the geographic relationships of the watersheds.

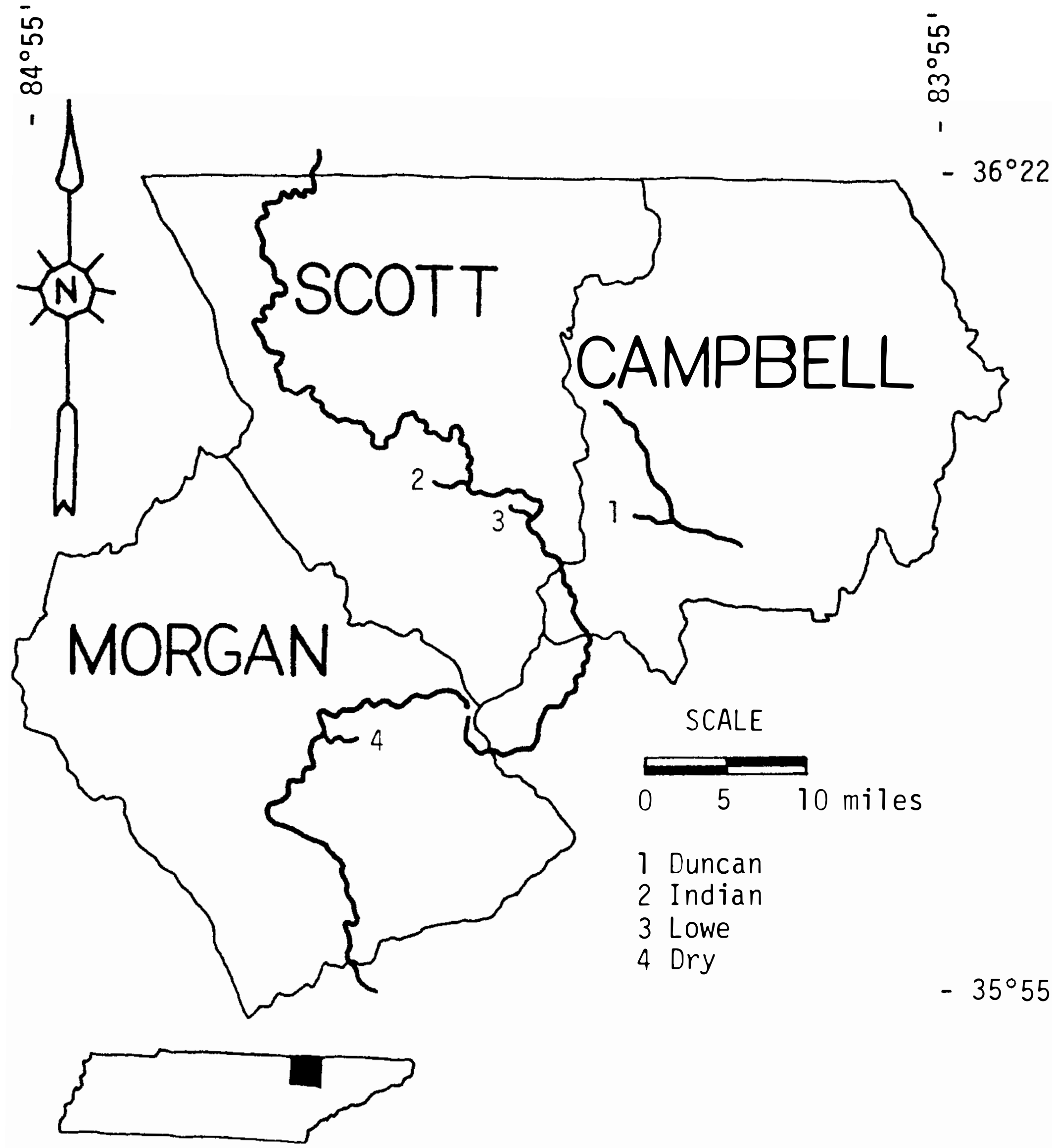

Figure 1. Geographic Relationships of the Four Study Streams.

The following data about the streams was taken from the geologic maps and mineral resources summaries published by the Tennessee Department of Conservation, Division of Geology. For Lowe Branch and Indian Creek, the Geologic Map and Mineral Resources Summary for the Norma Quadrangle (Avery and Luther, 1970; Luther and Avery, 1970) was used. Information about the Duncan Creek watershed was taken from the Geologic Maps and Mineral Resources Summaries for the Block and Duncan Flats Quadrangles (Luther, 1967; Statler and Sykes, 1970; Statler, 1970). The information about the Dry Branch area was inferred from the data about the adjacent Block Quadrangle as the data has not yet been published for the Gobey Quadrangle.

The watersheds are geologically similar. Exposed and underlying rock is Lower and Middle Pennsylvanian. Geologic sequences include the Crooked Fork formation which is exposed in the lowest evaluations of the Indian Creek study area, followed vertically by the Slatestone, Indian Bluff, Graves Gap, Redoak Mountain, and Vowell Mountain Formations. The youngest rock is the Cross Mountain Formation found in the highest elevation of the Duncan Creek watershed.

In addition to being similar geologically, the streams share other physical characteristics affecting their hydrology. Although there are some differences in the composition of the vegetation, all the streams drain watersheds covered by mixed deciduous and coniferous forest. Additionally, the streams are all relatively small, approximately 2-5 m wide where they were sampled, with alternating pool and riffle areas. Substrate was generally composed of rounded sandstone gravel and rubble with small amounts of sand and silt. Pools typically have a thin layer of silt overlying rocks. Duncan Branch differs somewhat from this overall picture in having more large boulders and fewer gravelly riffle areas. The Duncan substrate differs also in having a colorful gravel composed of bright pink bits of sandstone mixed with fragments of coal. A summary of watershed characteristics is presented in Table 1. A more complete description of each stream is presented below.

Lowe Branch has been part of the continuing study of the water quality, coal mining relationship since the initiation of the Appalachian Resources Project in 1975 (see Minear, et al., 1975-1980). Except for a mowed field near the confluence with the New River, the watershed is undisturbed. The stream flows eastward, draining the north side of Lick Creek Mountain and the southern slopes of Loyd Mountain. The watershed is approximately 245 hectares in size. Elevation change in the watershed is 1,520' with a low elevation of 1,180' at the confluence of Lowe Branch and the New River, and a maximum elevation of 2,700' on Lick Creek Mountain on the southern side of the watershed. The stream is shaded in summer throughout its course except for a small portion in the floodplain near the mowed field. Streamflow is seasonal with high water in the late winter and spring and low flow during late summer and fall. Although there is often little running water during the low flow periods, the remaining pools support populations of insects and fish.

Several coal seams are located in the Lowe Branch watershed, some of which are economically worth mining. The lowest is the Jellico seam at approximately 1,600'. The Windrock seam follows at 2,160' and the Big Mary (or Dean seam) at 2,220'. These seams occur on both the north and south sides of the watershed. The Walnut

Table 1. Summary of Watershed Characteristics for the Four Study Streams.

Characteristics	Dry Branch	Duncan	Lowe Branch	Indian Creek
Status	Disturbed approx. 25 years ago	Disturbed approx. 25 years ago	Control-undisturbed	Control-undisturbed
Watershed size	244 hectares	363 hectares	245 hectares	768 hectares
Geographic location	Morgan Co., south of Gobey	Campbell Co., north of Caryville, approx. 1.5 mi. on Hwy. 63	Scott Co., north of Smokey Jct.	Scott Co., at Cordell Bridge on New R.
Tennessee quadrangle map	Gobey	Block & Jacksboro	Norma	Norma
Watershed description above sample sites	One coal seam mined at 1800', probably Jellico. Forested watershed.	5 coal seams mined: Red Ash at 2480', Pee Wee at 2680', Rock Spring at 2760', Lower Wild Cat at 3120', Upper Wild Cat at 3180'. Forested watershed.	Forested. Old roadbed-unused.	Forested. Light cutting for firewood. Roadbed-lightly used.
Stream gradient	360'/mile	1000'/mile	288'/mile	270'/mile

Mountain and Pee Wee seams at 2,480' and 2,520', respectively, are present only on the southern, highest part of the watershed. Lowe Branch watershed is permitted for mining at elevations above 2,400' by Laco Mining Company, which is presently mining Anderson Branch watershed adjacent to Lowe Branch. According to Robert Walls, of Laco Mining Co., Pee Wee and Walnut Mountain coal will be stripped on the southern part of the watershed. Lowe Branch should be undisturbed, at least in theory, as the drainage will be diverted into the Anderson Branch watershed (Robert Walls, personal communication, 1980). Mineral rights at lower elevations are owned by Conrich and Richland Coal Company. It is not known if they have any plans to mine in the near future.

Indian Creek, the other control stream, is also a tributary of the New River in Scott County. It is located near the Cordell Bridge and is downstream and further north than Lowe Branch. Indian Creek is generally similar to Lowe Branch as it flows east to the New River through mixed deciduous and coniferous forest and has similar substrate characteristics. However, there are some differences in land use in the watershed. There are two sites on Indian Creek where small cornfields are occasionally planted, and there is sporadic logging for firewood in one area. The only homesite is near the confluence with the New River and is downstream from the sampling sites.

Indian Creek has the largest watershed of the study streams, 768 hectares. The elevation change is 1,040', from 1,160' at the confluence with the New River to 2,200' on Joel Dyer Mountain. Two coal seams are present in the watershed. The Poplar Creek seam at 1,240' lies at the top of the Crooked Fork Formation. Above this, at

1,640', is the Jellico seam. Other seams present in the Lowe Branch watershed, such as Pee Wee and Big Mary, are absent as they occur at higher elevations than are found in the Indian Creek watershed.

Duncan Creek watershed, strip mined for coal approximately twenty-five years ago is located in Campbell County near Caryville. Of the four study areas, this watershed attains the highest elevation, reaching 3,180' on Cross Mountain. The lowest point is 1,100' at the confluence with Cove Creek, giving a total elevation change of 2,080'.

Several coal seams are present in the Duncan Creek watershed, five of which have definitely been mined. The lowest seam, Coal Creek at 1,100', is reported unmined in the area; however, there is some evidence of a small cut. Above this at 1,500' lies the Jellico seam, followed by the Pioneer, Windrock and Big Mary seams at 1,960', 2,020', and 2,060', respectively. The first extensively mined seam, Red Ash, at 2,380' has been strip mined throughout the watershed and deep mined and augered in some places. Above the Red Ash, at 2,420', lies the unmined Walnut Mountain seam. The Pee Wee seam, following at 2,580', has been stripped except for a small portion at the northern tip of the watershed. Although the Red Ash and Pee Wee mines account for the major portion of mining in the Duncan Creek watershed, three other seams have been mined. The Rock Spring seam at 2,880' is stripped in the southern part of the watershed, and at the highest elevations of the watershed, the Upper and Lower Wild Cat seams have been stripped at 3,120' and 3,200'.

The lower elevation mine sites are revegetated except for a dirt road along the bench of the Pee Wee mine. There is much less recovery evident on the higher seams. These areas may not release much sediment to Duncan Creek, however, as there is no direct stream channel running through them. Additionally, they are located on nobs which are somewhat more level than the lower slopes, where the more extensive mines are located.

The second disturbed stream, Dry Branch, was mined during the same period as Duncan Branch. Dry Branch, in Morgan County, flows west off Bird Mountain, draining a 244 hectare watershed. Elevation change in the watershed is 1,280', with a maximum of 2,420' and a low point of 1,140' at the confluence with the Emory River.

The three prongs of the creek drain the steep southern slope of the watershed where the Jellico seam was mined at approximately 1,720'. This seam has been extensively mined on Bird Mountain. The bench and outslope are now revegated in most areas, but there is evidence that the bench is used as a motorcycle trail, and some areas of the high wall are covered with a bare, loose, shaley material. The northern side of the watershed is lower and there is no present disturbance other than a dirt road which has light use.

CHAPTER III

MATERIALS AND METHODS

Sampling Procedures

In order to compare the four streams and evaluate similarities and differences among them, benthic samples were collected monthly for six months from each stream. A sampling period of six months, January through June, was chosen to incorporate at least some seasonal change within the community. Although biomass and numbers of individuals are variable in streams depending on local conditions, in temperate areas the greatest numbers are present in summer and autumn due to recruitment (Hynes, 1970). However, these individuals may be very small and difficult to identify. Sampling for this study was conducted from winter through early summer, a time when there are many mature individuals present. By sampling each month, it was possible to detect fluctuations in the abundance of different taxa and the density of individuals in an area. At this point taxa will be defined as a naturally related group of animals. In some of the data analysis the term "taxa" is used rather than "species." This is because of the difficulty of identifying many of the immature aquatic insects (reliably) to the species level and generally indicates that all of the groups in the discussion have been identified as accurately as possible.

A main objective of the study was to sample a comparable habitat in each stream so that differences between streams could be examined. To accomplish the comparison, a stratified random sample was taken in similar riffles in each stream. Stratified sampling reduces between habitat differences and helps minimize variance within samples (Tanner, 1978). Riffles were chosen as sample sites as they have a characteristically rich fauna (Hynes, 1970), and were found by Gaufin, et al. (1956) to provide a greater sampling efficiency due to a more homogeneous distribution of fauna, than pools or margins of streams. By sampling riffles in each stream, between habitat differences were minimized as much as possible, and ecologically similar areas in each stream were compared. Although it was recognized that time of day, temperature, light intensity, etc., might affect the behavior and distribution of benthic invertebrates, there was no attempt to control for these factors due to the improbability of sampling these four streams under the same environmental conditions.

One problem in attempting a quantitative study of natural communities lies in collecting a large enough sample to allow an accurate description of the community. This is because the different populations tend to have a clumped distribution rather than being evenly dispersed. There have been attempts to deal with this problem reported by various authors including Southwood (1978), Needham and Usinger (1956) and Hynes (1970). In the present study, eight sub-samples, each .18 m^2 (2 $ft.^2$) in area, were taken using either a Surber Sampler or a bottom net. This sample size was adopted from previous research on Cumberland Mountain streams (Tolbert, 1978) and provides a total sample area of 1.44 m^2. It is felt that this area of stream collected monthly for six months provided a reasonable estimate of the benthic community while not being too large to process.

When the study began in January 1979, samples were taken using a bottom net with a round 12" diameter frame and mesh openings of approximately .6 mm as a modification of the Surber method developed by Tolbert (1978). She used this net as it is more flexible than a Surber Sampler and could be pressed flat against rocky substrate in riffles. Each subsample was collected by estimating a 1 $ft.^2$ area upstream from the net, then turning all large rocks within the area by hand and removing any animals so the current carried them into the net. Once the large rocks had been examined, the gravelly substrate was stirred so the current would wash the animals that burrow or live in interstitial spaces into the net. After one $ft.^2$ had been collected, the net was moved to an adjacent area and another area was collected the same way before the net was emptied. In April, 1979, and the following months of the study, a square foot Surber Sampler was used to ensure that the area collected was accurately measured. Each sample was preserved in the field in 95% ethanol. After the samples were sorted, the insects were stored in 80% ethanol.

In addition to the regular sampling of benthos, light trapping of adults and laboratory rearing of immatures was used to supplement and verify identifications, as the taxonomy of adult insects is often more completely worked out than that of the immatures.

A Nikkon dissecting scope was used in making identification determinations. The primary references used for identifications were: Plecoptera, Ricker (1952), Hitchcock (1974), Fiance (1977), Frison (1942), and Dr. Bill Stark (personal communication, 1980); Ephemeroptera, Edmunds, et al. (1976), Morihara and McCafferty (1979), Allen and Edmunds (1962, 1963, 1965), Lewis (1974);

Trichoptera, Wiggins (1977), Ross (1944, 1946), Flint (1960, 1962), Flint and Wiggins (1961), Schmid (1970), Schuster and Etnier (1978); Diptera, Ussinger (1965), Merrit and Cummins (1978), Hilsenhoff (1975); Coleoptera, Usinger (1956), Brown (1976), Merrit and Cummins (1978); Megaloptera, Tarter (1976).

Physical and chemical water quality parameters were also measured when each stream was sampled for insects. Field analysis consisted of measuring water temperature, and dissolved O_2 with an Orion oxygen meter, pH with a Yellow Springs Instrument Company pH meter, and water velocity with a Teledyne Gurley No. 625 Pygmy Current Meter. On several occasions velocity was measured approximately three centimeters above the substrate at three different sites within the riffles where insect samples were taken.

Two 250 ml Nalgene bottles were filled with stream water at the sampling site for laboratory analysis of chemical parameters, including alkalinity and hardness (measured as mg/l $CaCO_3$) and dissolved iron and sulfate concentrations. Bausch & Lomb SpectroKits and a Bausch & Lomb Spectronic mini 20 spectrophotometer were used to evaluate these parameters according to Standard Methods (American Public Health Association, 1975). The pH values were also measured in the laboratory on occasions when field equipment was not functional.

Additionally, there was laboratory analysis of suspended solids, including the organic and fixed components following the directions given by Millipore Bulletin AB 312 which complies with Standard Methods (American Public Health Association, 1971).

Data Analysis

For the purpose of determining if there were significant differences both among the four streams, and between the streams as two groups, mined and unmined, the benthic data were analyzed both quantitatively and qualitatively. Among the multitude of analytical techniques available for benthic data (TVA, 1977; EPA, 1973; Green, 1978; Hilsenhoff, 1977), several simple measures were chosen. These are the density of individuals for the total sample area (1.44 m^2), species richness (= number of taxa in this study), and species diversity (again using taxa).

Although species diversity is not universally accepted by aquatic biologists, diversity is commonly used in water quality analysis (EPA, 1973; TVA, 1977; Kaesler, et al., 1978; Wilhm and Dorris, 1968) for evaluating effects of pollution on aquatic systems. Species diversity was used in the present study in conjunction with the other parameters to provide a broad picture of the stream community as it is a combined measure of species richness and the distribution of individuals among the species. The index used is that described by Shannon and Weaver (1963) as

$$H' = -\sum_{i-1}^{S} P_i \log P_i$$

where

s is the number of species

P_i is the proportion of the total number of individuals consisting of the ith species.

Density, species richness and diversity were compared among the streams by use of two-way analysis of variance (anova) (Sokal and

Rolf, 1969). This technique serves to separate variations among the means to determine if the samples came from different populations. Significant differences are examined by use of Student-Newman-Keuls means separation tests (Sokal and Rolf, 1969; Chapter 13, Zar, 1974).

Qualitative differences among the streams were examined to determine if the faunas of the streams were taxonomically similar. Community composition was compared at the level of order, family, genus and species (when possible) by totalling the numbers of individuals in each taxa for the sampling period. Additionally, the proportions of abundant taxa in each stream were computed for the numerically most important orders. Thus each stream could be evaluated in terms of what portion it contained of the pooled taxa from all streams. Common taxa were compared so that those taxa with only a few individuals would not overly influence the results.

Finally, in addition to examining the proportions of the total taxa present in each stream, the streams were compared using a modified coefficient of similarity (Cn), a measure of the similarity of the taxa in different habitats (Southwood, 1978). The formula is $Cn = 2jn/(aN + bN)$ where aN = the total individuals sampled in habitat a, bN = the same in habitat b, and jN = the sum of the lesser values for the species common to both habitats. Similarity coefficients have been used by different researchers to study changes induced by pollution by comparing damaged and undisturbed areas. They are particularly useful because they are in a sense calibrated to local conditions (Hilsenhoff, 1977).

CHAPTER IV

RESULTS

Quantitative Analysis of Benthic Samples

A summary of the quantitative data is presented in Table 2. Section A contains species diversity values computed monthly and for the total sampling period. Section B presents the number of taxa collected monthly and cumulatively. The monthly density of individuals/1.44 m^2 and totals for the six month period are shown in Section C.

One of the most obvious differences among the streams is the greater total number of individuals collected from the unaffected streams over the six month period. To determine if these differences were statistically significant, the streams were compared by use of a two-way anova testing the numbers of individuals collected monthly for the six month period. Results are shown in Table 3. Significance was determined at the level of $\alpha = .05$. In this and following anova's, symbols will be as follows: df, degrees of freedom; SS, sum of squares; MS, mean squares; and F, the test value. Anova results indicate significant differences among the streams in terms of density of individuals/1.44 m^2. Differences among months were not significant. A Student-Newman-Keuls means separation test (Figure 2) was used to determine which streams were different from which other streams. Again, significance was determined at the .05 level. The test puts the streams into three overlapping groups formed by Lowe Branch and Indian

Table 2. Species Diversity, Number of Taxa and Density of Individuals/1.44 m^2 for the Sampling Period.

Category		Dry Br.	Duncan Cr.	Indian Cr.	Lowe Br.
A. Species Diversity Monthly	J	2.35	2.10	2.90	2.66
	F	2.71	2.46	2.60	2.24
	M	2.44	2.81	2.74	2.79
	A	2.59	2.44	2.72	2.51
	M	2.35	2.42	2.97	2.33
	J	2.42	2.68	2.43	2.44
For 6 months		3.12	3.15	3.39	3.06
B. Number of Taxa Monthly	J	29	17	36	42
	F	31	25	38	31
	M	29	29	41	39
	A	30	29	40	33
	M	28	31	35	31
	J	32	34	39	34
For 6 months		62	63	70	68
C. Density of Individuals/ 1.44 m^2	J	282*	147*	402	534
	F	207	237*	574	719*
	M	435	170	524	476
	A	605	298	663	554
	M	629	421*	519	694
	J	361	537	1116	829
Total number collected		2519	1810	3798	3806

*Number of individuals adjusted to 1.44 m^2 sample size to compensate for missing or extra samples.

Table 3. Analysis of Variance of Density of Insects/1.44 m^2 in Study Streams for Six Months.

Source	df	SS	MS	F	
Streams	3	.491	.164	7.72	*
Months	5	.298	.060	2.82	NS
Error	15	.318	.021		
Total	23	1.107			

*Significant at the .05 level; NS = Not significant.

1	2	3	4
Duncan Creek	Dry Branch	Indian Creek	Lowe Branch
2.433	2.592	2.754	2.795

Figure 2. Student-Newman-Keuls Means Separation Test of the Density of Individuals/1.44 m^2 in Study Streams.

Creek (both undisturbed), Duncan Creek and Dry Branch (both mining-disturbed), and Dry Branch and Indian Creek (one disturbed, one undisturbed).

In addition to having a greater density of individuals, the undisturbed streams have greater species richness, both monthly and cumulatively. To determine if differences were statistically significant, the streams were compared using the number of taxa collected monthly for the six month period. Results of the two-way anova are shown in Table 4. Significance was determined at the .05 level. Figure 3 shows differences among the group means as indicated by the SNK test, also tested at the .05 level. Again the streams fall into three overlapping sets of mining-affected, undisturbed, and a "mixed" category. This mixed set is different from the previous set, however, as Dry Branch is now more similar to Lowe Branch than to Indian Creek.

Monthly species diversity values were compared using a two-way anova. Results are shown in Table 5 and indicate no significant differences among the streams.

Qualitative Analysis of Benthic Samples

Statistical analysis of the data indicates that the four streams form two groups, mined and unmined, based on differences in density of individuals and species richness. In each case a third set composed of the undisturbed and disturbed streams which are most alike is also formed. There were no statistical differences based on species diversity. It remains for a qualitative analysis to determine the basis for the observed differences between the groups of streams.

Table 4. Analysis of Variance of Number of Taxa in Study Streams for Six Months.

Source	df	SS	MS	F	
Streams	3	3.363	1.121	7.52	*
Months	5	.523	.105	.70	NS
Error	15	2.236	.1491		
Total	23	6.122			

*Significant at the .05 level; NS = Not significant.

1	2	3	4
Duncan Creek	Dry Branch	Lowe Branch	Indian Creek
5.215	5.461	5.906	6.167

Figure 3. Student-Newman-Keuls Means Separation Test of the Number of Taxa in Study Stream.

Table 5. Analysis of Variance of Species Diversity in Study Streams for Six Months.

Source	df	SS	MS	F	
Streams	3	.263	.088	1.92	NS
Dates	5	.120	.024	.53	NS
Error	15	.686	.046		
Total	23	1.069			

NS = Not significant at the .05 level.

Figure 4 shows the percentage composition by order of the total fauna collected from each stream over the six month period. Only the orders which formed major components of the fauna are represented here. From the shape of the bar graph it is apparent that the streams have strong similarities; most notable is the dominance of the mayfly (Ephemeroptera) fauna in all streams. Additionally, the stoneflies (Plecoptera), flies (Diptera), and beetles (Coleoptera) each comprise a similar component of the fauna in all streams. Orders which are most different among the streams are the caddisflies (Trichoptera) with Dry Branch and Lowe Branch being widely separated, and the Isopoda which are essentially absent from all streams except Duncan Creek. That the streams do not separate into the categories of mined and unmined, based on the percentage composition of the different orders, indicates the decreases in density and species richness observed in the disturbed streams are not due to the absence of a major component of the fauna present in undisturbed streams, and suggests an overall reduction in numbers.

Since the proportions of the orders represented in the different streams were similar, the number of individuals in each order was examined to compare the two groups of streams. The two categories of streams were compared to help determine which orders contributed most to the overall differences in densities of individuals between groups of streams. Figure 5 presents total numbers of individuals collected for six months in the most important orders with the mined and unmined streams grouped. This graph reveals the depression of numbers in the disturbed streams in all orders except Trichoptera. The Ephemeroptera and Diptera show the most severe reduction in numbers, having 50% and

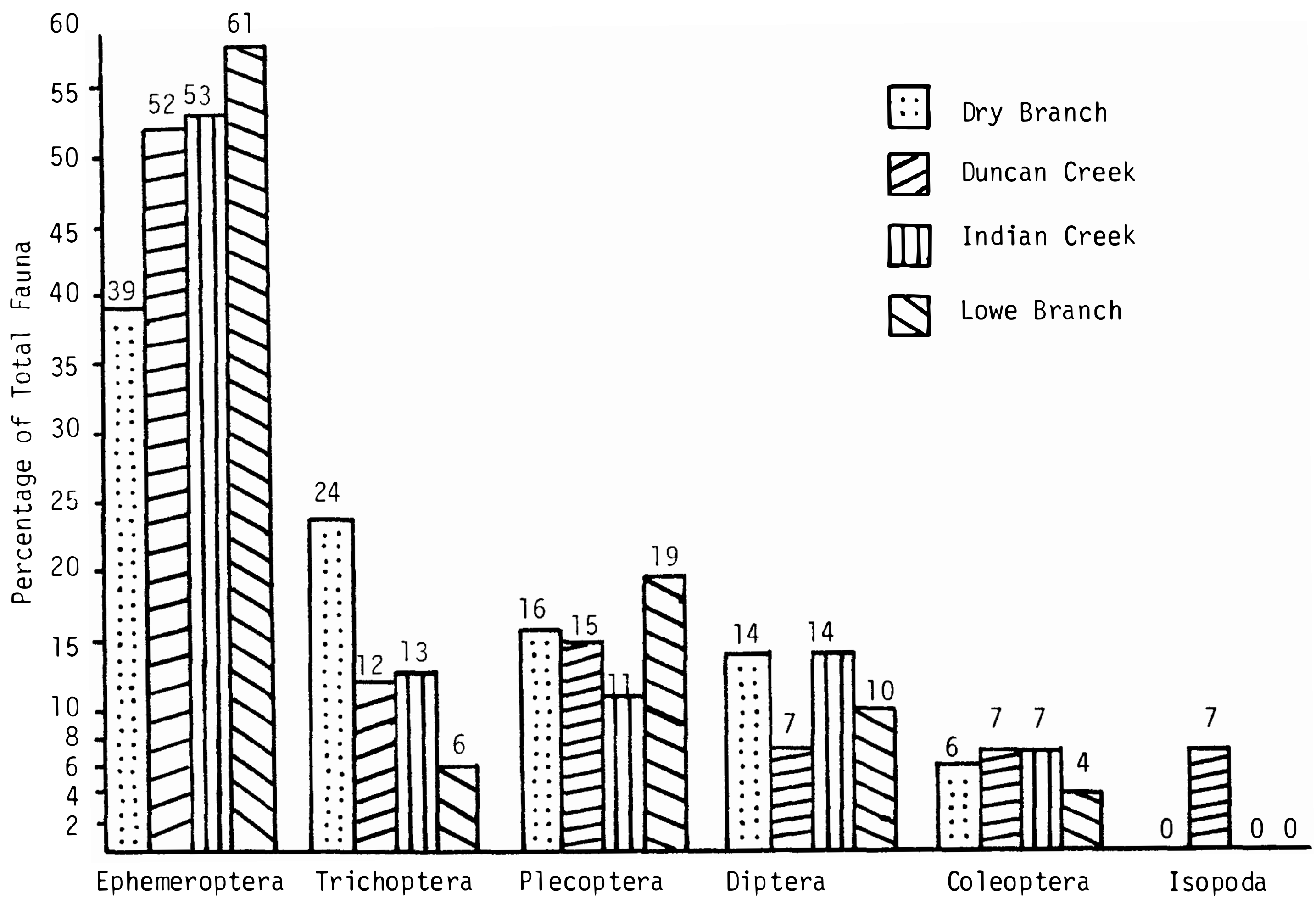

Figure 4. Percentage of Total Fauna in Each Stream Contributed by Each Order.

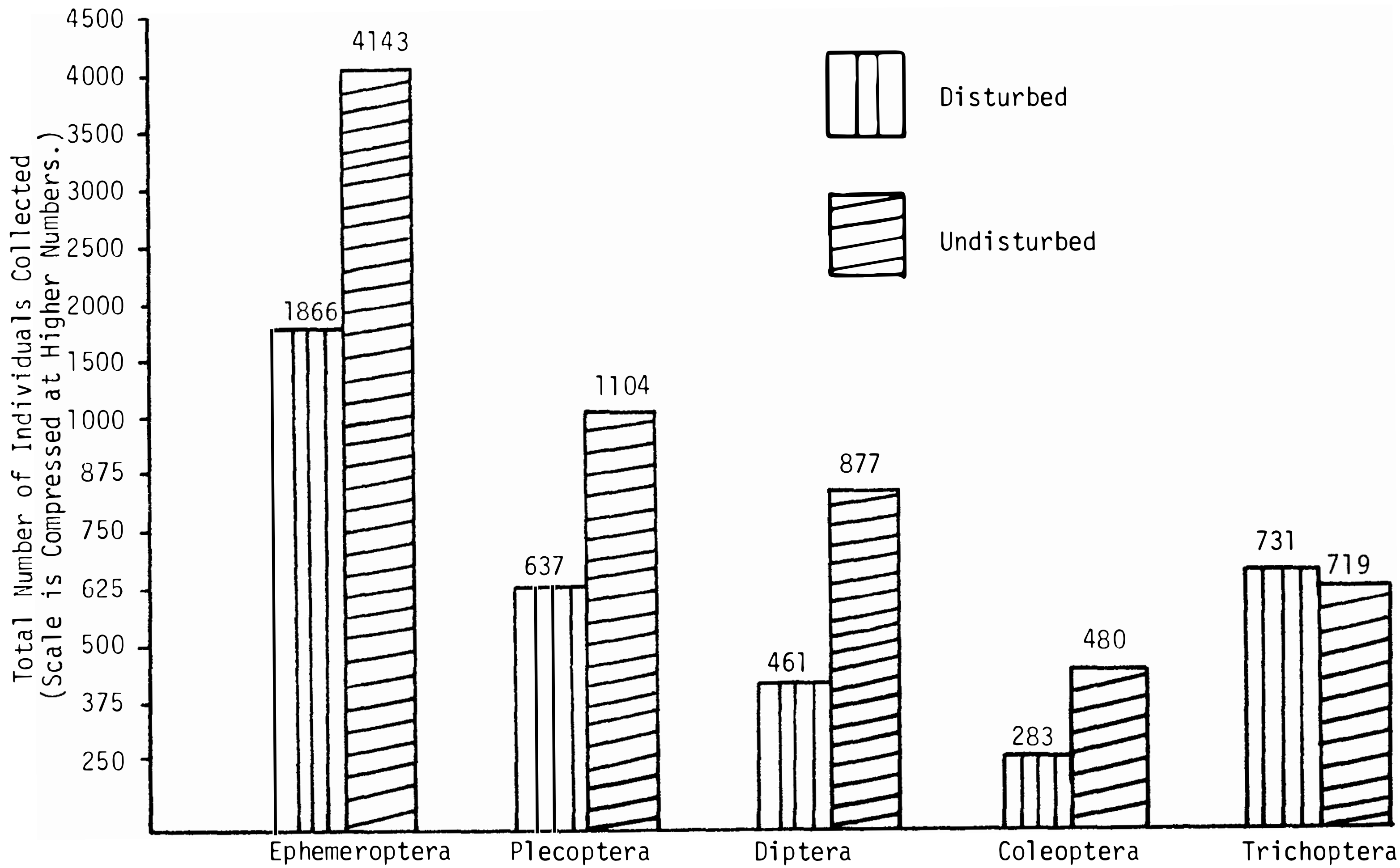

Figure 5. The Total Number of Insects Collected in Each Order from Disturbed and Undisturbed Streams for the Total Sample Period.

53%, respectively, of the individuals in the undisturbed streams. The exception to this condition is the order Trichoptera, with numbers being approximately equal for the two categories.

To determine which components of the different orders contribute to the observed differences, it is necessary to examine more basic taxonomic units within the orders. Community composition at the level of family, genus, and species (where possible) for the orders Ephemeroptera, Plecoptera, and Trichoptera is presented in Tables 6, 7, and 8, respectively. Diptera, Megaloptera, Crustacea and Coleoptera are presented in Table 9. For the orders Ephemeroptera, Plecoptera, and Trichoptera, Table 10 presents the percentage of the total taxa collected for each order present in each stream.

Ephemeroptera. Examination of the numbers of individuals in the taxa of this order reveals that there are fewer rare taxa (chosen as those with less than five individuals) in Duncan Creek and Dry Branch which have only 57% and 47%, respectively, of the total mayfly taxa collected from all streams. Comparatively, Indian Creek and Lowe Branch each have 84% of the total. Of particular interest is the genus Stenonema which is populous in the undisturbed streams, but has a total of only seven individuals in the disturbed streams. The reduced numbers of taxa present in abundance and the numerous taxa with few individuals indicates an overall reduction of numbers of mayflies in the mining affected streams. Although there are some taxa not collected in the disturbed streams, they are typically groups with a few representatives in the undisturbed streams and do not contribute a large number of individuals to any streams.

Table 6. Distribution of Taxa of Ephemeroptera Among and Within the Streams.

Taxon	Dry	Duncan	Indian	Lowe
Heptageniidae	325	452	764	824
Cinygmula subeaqualis	3	105	175	188
Epeorus	273	305	243	428
Stenonema 1	0	6	113	127
Stenonema 2	1	0	86	22
Stenacron gildersleevei	1	3	15	9
Heptagenia 1	1	32	40	44
Heptagenia 2	46	1	42	6
Ephemerellidae	85	167	88	470
Ephemerella dorothea	78	131	51	143
E. cornutella	1	36	36	321
E. (Danella)	6	0	0	6
Leptophlebiidae	119	21	393	361
Paraleptophlebia 1	6	13	16	8
Paraleptophlebia 2	50	1	256	251
Habrophlebiodes	63	7	118	100
Habrophlebia vibrans	0	0	3	2
Baetidae	228	229	719	438
Pseudocloeon	0	93	66	4
Centroptilum	0	2	6	12
Baetis spp.	227	133	573	418
B. hageni	1	1	74	4
Siphloneuridae	194	43	4	80
Ameletus lineatus ?	194	43	4	80

Table 7. Distribution of Taxa of Plecoptera Among and Within the Streams.

Taxon	Dry	Duncan	Indian	Lowe
Perlidae	0	30	15	74
Acroneuria carolinensis	0	22	3	46
A. abnormis	0	8	6	28
Eccoptura xanthenes	0	0	6	0
Perlodidae	98	32	41	66
Remenus bilobatus	0	0	8	4
Isogenus hastatus	98	31	18	55
Isoperla orata	0	1	15	7
Peltoperlidae	5	2	2	9
Peltoperla	5	2	2	9
Nemouridae	8	21	24	19
Amphinemura delosa	6	17	11	16
A. wui	1	0	0	2
Nemoura (s.l.)	1	4	13	1
Chloroperlidae	91	36	37	86
Sweltsa mediana ?	82	34	31	71
Hastaperla brevis	9	2	0	12
Alloperla sp.	0	0	6	3
Leuctridae	67	44	100	151
Leuctra	67	44	100	151
Capniidae	97	83	43	274
Paracapnia opis	2	82	21	268
Allocapnia	95	1	22	6
Taeniopterygidae	14	9	131	21
Brachyptera	14	9	131	21
Taeniopteryx	0	0	11	0

Table 8. Distribution of Taxa of Tricoptera Among and Within the Streams.

Taxon	Dry	Duncan	Indian	Lowe
Hydropsychidae	112	167	227	84
Diplectrona modesta	62	84	17	53
Cheumatopsyche	1	20	164	3
Symphitopsyche ventura	4	28	6	9
S. sparna	0	15	5	9
Hydropsyche betteni (grp.)	0	5	0	0
Hydropschidae unknown genera (small)	45	15	31	10
Glossosomatidae	3	10	4	0
Glossosoma nigrior ?	3	10	4	0
Rhyacophilidae	10	8	1	5
Rhyacophila parantra	5	4	1	3
R. fuscula	1	2	0	0
R. 5 (carolina ?)	0	2	0	0
R. sp.	4	0	0	2
Limnephilidae	233	24	131	101
Neophylax cf. *aniqua*	92	3	0	0
N. cf. *concinnus*	105	19	130	89
Pycnopsyche gentilis	29	1	1	3
P. sp.	4	0	0	4
Goera stylata	1	1	0	3
Philopotamidae	13	2	59	10
Wormaldia	13	2	11	9
Dolophilodes distinctus	0	0	48	1
Lepidistomatidae	193	1	25	24
Lepidistoma spp.	193	1	25	24
Polycentropodidae	2	13	34	12
Polycentropus	2	13	34	12

Table 9. Distribution of Taxa of Diptera, Megaloptera, Coleoptera and Crustacea Among and Within the Study Streams.

Taxon	Dry	Duncan	Indian	Lowe
DIPTERA				
Tipulidae	164	24	160	142
Tipula	15	6	13	21
Hexatoma 1	145	18	127	117
H. 2	0	0	9	2
Dicranota	4	0	11	2
Simuliidae	14	10	12	3
Simulium	8	8	8	0
Prosimulium	6	2	4	3
Chironomidae	155	78	326	210
Ceratopogonidae	7	2	21	2
MEGALOPTERA				
Corydalidae	8	1	42	5
Nigronia fasciatus	5	1	1	4
N. serricornis	3	0	41	1
COLEOPTERA				
Psephenidae	140	127	220	115
Psephenus herricki	140	127	220	115
Elmidae	10	1	39	9
Optioservus	3	0	26	7
Stenelmis	1	1	4	1
Dubiraphia spp.	6	0	9	1
Dryopidae	4	0	8	1
Helichus	4	0	8	1

Table 10. Percentage of Taxa of Ephemeroptera, Plecoptera, and Trichoptera.

Taxa Information	Dry	Duncan	Indian	Lowe
Ephemeroptera				
Taxa with less than five individuals	9	11	16	16
Percentage of total taxa of Ephemeroptera	47	57	84	84
Plecoptera				
Taxa with less than two individuals	8	9	15	14
Percentage of total taxa of Plecoptera	44	50	83	78
Trichoptera				
Taxa with more than two individuals	12	11	11	9
Percentage of total taxa of Trichoptera	57	52	52	43

Plecoptera. The stonefly fauna in the disturbed streams follows a pattern similar to that of the mayflies. Fewer taxa of the total stonefly fauna are present in abundance (greater than two individuals for Plecoptera). The disturbed streams have 44% and 50% of the total stonefly taxa in all streams, compared to 78% and 83% in the undisturbed streams. There is one interesting absence in Dry Branch, a disturbed stream, as there were no individuals in the family Perlidae collected from this stream for the total sampling period. The other streams have two or three species of *Acroneuria* (Perlidae) present. Among the streams there are additional taxa absent also, but no other taxa at the level of family is missing from one stream and well represented in others.

All streams show substantial variability regarding the distribution of individuals within families, genera, and species, with no apparent comparability of streams. For instance, perlodids are numerically most abundant in Dry Branch, but with only one species collected; whereas Indian Creek and Lowe Branch both have three species each, but fewer total individuals. Another example is the genus *Allocapnia*. There were 95 individuals collected in Dry Branch, 1 in Duncan Creek, 22 in Indian Creek, and 6 in Lowe Branch.

Trichoptera. Of the orders comprising a major segment of the fauna in all streams, caddisflies are most evenly distributed between the two groups of streams, as both categories have approximately equal numbers of individuals. However, the distribution among individual streams is quite variable. In Dry Branch, for instance, the genus *Lepidistoma* (Lepidistomatidae) is abundant, having almost eight times as many individuals as any other stream. As another example, the family Hydropsychidae is represented in noticeably different degrees in the different streams, accounting for 74% of the Trichoptera in Duncan Creek, but only 20% of those in Dry Branch.

The percentage of abundant taxa of Trichoptera in each stream reveals the variable nature of the distribution, as each stream has an approximately equal number of taxa.

Diptera. As with mayflies and stoneflies, the total numbers collected from the undisturbed streams is higher than from the mining-affected streams. Duncan Creek has the fewest individuals in all families. Dry Branch has the most in the family Tipulidae, but has fewer Chironomidae than either Indian Creek or Lowe Branch. The percentage of abundant taxa was not computed for this or succeeding orders due to the taxonomic difficulty of the groups or the relatively few taxa which were collected.

Coleoptera. Indian Creek has substantially more beetles than any of the other three streams, which have similar numbers collected. The water penny, *Psephenus herricki*, accounts for the vast majority of individuals collected from any stream.

Megaloptera. Representatives of the order, primarily the genus *Nigronia*, were present in all streams. Indian Creek had an abundance of the species *N. serricornis*.

Crustacea. Crustaceans, particularly crayfish, were present in all streams, but were not routinely kept as part of the benthic samples. Smaller types, Isopoda and Amphipoda, were treated the same as the insects. The order Isopoda was common in Duncan Creek, with as many individuals as the Coleoptera. The only other creek with Isopoda was Lowe Branch which had only three individuals. A few Amphipods were collected but are not represented in Table 9.

Similarity Coefficient

The following information presents the index values for the four study streams with each stream being compared to each other stream. The values are tabulated for the six month period to minimize monthly sample variability.

Streams	Lowe	Indian	Dry
Indian	.67		
Dry	.55	.51	
Duncan	.54	.46	.58

Indian Creek and Lowe Branch, with an index value of .67, have the most similar faunas. Duncan Creek and Dry Branch are the next most similar with an index value of .58. The least similar for the total period is Duncan Creek and Indian Creek with a .46 value.

The high index value for Indian Creek compared to Lowe Branch results from the large numbers of individuals in several shared taxa of mayflies in the families Heptageniidae, Leptophlebiidae, and Baetidae; of true flies, Chironomidae and *Hexatoma*; and the beetle *Psephenus herricki*. Taxa shared between Duncan Creek and Dry Branch have a somewhat different distribution, with fewer mayfly taxa having large numbers of individuals. The most important shared taxa are the mayflies *Epeorus*, *Ephemerella dorothea*, and *Ameletus*; the stoneflies

Malirekus hastatus and *Sweltsa* (probably *mediana*); the caddisfly *Diplectrona modesta* and the water penny, *Psephenus herricki*.

Water Quality Data

Water quality data for the six month period are presented in Table 11. Mean values for those parameters affected by mining are shown also. Three of the streams, Dry Branch, Lowe Branch, and Indian Creek all have similar water quality. In all three alkalinity varies from 5-10 mg/l, hardness from 10-20 mg/l, and SO_4 averages less than 8 mg/l, with the highest value being 30 mg/l from Indian Creek. In contrast, Duncan Creek shows an elevation of the above parameters characteristic of the effects of strip mining in the area. In Duncan Creek alkalinity averages 19 mg/l and varies between 15 and 30 mg/l. Hardness values range from 40-120 mg/l with the average being 62 mg/l. SO_4 also is elevated; the highest reading during the six month period was 140 mg/l. The mean was 61 mg/l.

Suspended solids concentrations were low in all streams. The highest values were recorded at Indian Creek and resulted from a dirt road which parallels the stream and was quite muddy during wet weather. During a high flow period, Indian Creek showed 60.4 mg/l, the largest value recorded. Values generally were less than 10 mg/l for Indian Creek and the other streams.

Table 11. Water Quality Data from January-June 1979.

Stream	Dates	Temp. °C	O_2 ppm	pH	Alk[b]	Hardness[b]	SO_4[c]	Fe[c]	SS_t[d]	SS_f[d]	Average Velocity
Dry	1-4	2.5	9.2	6.2	10	10	5	.03	2.0		
	2-15			6.5[a]	10	20	10	.00	28.8		
	3-13				10	10	2	.08	2.4	.8	.5 m/s
	3-23	10.0	7.2	7.7	10	10	1	.18	15.2	11.6	
	4-23	15.0	6.8	6.5[a]	10	20	0	.03	6.4	4.0	
	5-14	17.0	9.7		10	10	12	.02	4.4	1.6	.4 m/s
	6-26	21.0	8.4	7.0[a]	10	20	15	.05	3.2	1.2	
	$\bar{X}$				10	14	6.4		9.0		
Duncan	1-12	3.0	9.5	6.2	20	40	26	.00	4.4		
	1-30	4.0	9.6	6.6	15	40	36	.01	3.0		
	2-08	15.0	15.0	6.6	20	80	44	.02	5.2		
	3-13				15	40	40	.03	2.0	.08	.5 m/s
	4-11				15	40	140	.18	20.0	16.4	
	5-19	17.5	7.2	6.5	15	60	45	.03	16.0	13.2	
	6-06	18.0	8.6	7.2	20	60	60	.00	11.6	9.6	
	6-12				25	80	70	.03	8.4	5.6	
	6-22				30	120	90	.04	2.8	1.6	.7 m/s
	$\bar{X}$				19	62	61		8.0		
Indian	1-04	3.0	9.0	6.1	5	10	2	.02	4.4		
	2-22	7.0	10.7	6.8[a]	10	10	7	.00	4.8		.7 m/s
	3-13				10	10	3	.03	22.0	18.8	.5 m/s
	3-23	7.5	7.0	7.5	5	10	2	.13	60.4	54.0	
	4-10	12.0	7.2		10	10	5	.13	10.4	6.4	
	5-14				5	20	30	.03	4.8	3.6	.3 m/s
	6-12				5	10	12	.08	8.0	4.8	
	$\bar{X}$				7	11.4	7		16.4		
Lowe	1-11	6.0	7.8	6.1	5	10	20	.10	2.4		
	2-14			7.1[a]	10	10	0	.00	.0		
	3-23	13.0	7.9		10	10	5	.03	3.6	2.0	
	4-10	13.0	7.0		10	10	17	.04	8.4	6.4	
	5-11	19	9.0	6.5	5	10	2	.09	4.8	2.8	
	6-06	18	8.2	6.4	5	10	2	.02	4.0	2.8	
	6-12				10	20	4	.00	4.0	1.6	.3 m/s
	$\bar{X}$				8	11.4	7		4.5		

[a]pH measured in laboratory due to field equipment problems.

[b]Alkalinity and hardness expressed as mg/l $CaCO_3$.

[c]SO_4 and Fe expressed as mg/l.

[d]Suspended solids fixed and total expressed as mg/l.

CHAPTER V

DISCUSSION

Use of quantitative data analysis allows the four streams to be grouped into two categories, mining-affected and unaffected, based on differences in the density of individuals per sampling unit and the numbers of taxa collected each date. Qualitative analysis reveals that disturbed stream differences are due both to an overall reduction of numbers of individuals in many taxa and low numbers of certain taxa which are abundant in the undisturbed streams. Analysis of community similarity (Cn) among all streams indicated the highest similarity between undisturbed streams and next highest between disturbed streams. The Cn values indicate the importance of such taxa as those in the mayfly family Heptageniidae which are abundant in the undisturbed streams, but are notably reduced in the affected streams.

One measure of stream condition, the diversity index (H'), indicated no significant differences between the streams. H' is a measure of species richness and the distribution of individuals among the species. It was used in the present study in conjunction with other indicators to give a broad picture of community structure; used alone the implication would be that the streams are very similar. Examination of density and species richness indicates otherwise.

The observed differences could result from many factors which can be grouped into two categories for the purposes of this research: (1) the effects of coal mining and (2) everything else. Everything else, a very broad category, includes the inherent variability in the watersheds resulting from:

1. Differences in drainage basin.
2. Differences in watershed size.
3. Hydrological differences.
4. Aspect of the streams.
5. Local influences of climate.
6. Quality and quantity of food source and retention time in streams.
7. Source of colonizers and history of succession.
8. Land use practice following coal mining.

All of these factors may be contributing to the differences between the two groups of streams and cannot be discounted. However, a major assumption of this project is that the streams, even after twenty-five years, might still be influenced by previous mining history. In order to make this assumption reasonable, the streams were chosen to be as similar as possible while meeting the mining history criteria. As aquatic insects are specialized in their habitat requirements, ecologically similar areas of different streams may have a fauna more similar than heterogeneous habitats within the same stream (Hynes, 1970). Thus the riffle areas sampled were selected to be similar in substrate characteristics (gravel and rock approximately 2-10 cm in diameter), depth (4-15 cm) and velocity (average .3-.7 m/s).

Assuming that the differences are at least partially a response to mining disturbance, it is necessary to examine contributing factors. Of prime importance is the length of time required for habitat recovery.

Although there is a relatively quick drop in the very high concentrations of suspended sediment after the cessation of active mining, concentrations may still often exceed 100 mg/l five years after the cessation of mining. This slow abatement of periodic high suspended solids serves to prolong the habitat alteration resulting from the settling of sediment over the stream substrate. The unconsolidated silt on the stream bottom provides an unsuitable habitat for drifting organisms and also for those that might recolonize by moving upstream.

In addition to a slow physical recovery of stream habitat following strip mining, the mining process often affects potential recolonization. Typically a mining cut will follow a coal seam at a given elevation as far as possible, perhaps affecting several adjacent watersheds. If the disturbance is high across these watersheds, there may be no unaffected stream source for recolonization. As downstream drift is the major and fastest mechanism for recovery, recolonization of the damaged area may be greatly retarded.

Since both of the affected streams have a somewhat different history and drain into different river systems, the specific sources of recolonization will be discussed separately for these two streams.

Duncan Creek, in Campbell County, is a tributary of Cove Creek near Cove Lake State Park in Caryville, Tennessee. A total of five coal seams have been mined in the Duncan Creek watershed. All of them are located near or above the headwaters of the creek and would have greatly reduced downstream drift for recolonization. Thus, repopulation would have to be from either residual populations or from another stream. Cove Creek is a larger creek than Duncan, being about 30 to 40 feet wide near their confluence, but it is shallow with a rocky bottom and riffles, and provides a habitat somewhat similar to that of Duncan Creek. Although Cove Creek might have had a similar fauna to Duncan Creek, it too is impacted by extensive strip mining of the area it drains, and may not have supported substantial populations of individuals to repopulate Duncan Creek.

The situation in Dry Branch is similar, although it perhaps is affected even more by the lack of a suitable recolonization source. While there was only one seam mined in the watershed, compared to five in Duncan, the mining cut is at or near the headwaters of the stream, eliminating downstream drift as a good source for recolonization. Additionally, the Emory River, of which Dry Branch is a tributary, provides a much different habitat from that of the small stream and supports a different fauna. Those species that would be able to live in Dry Branch would have had to migrate upstream across the floodplain, which is planted with corn. Riparian vegetation like a cornfield may be unattractive enough to have discouraged adults from migrating upstream to oviposit.

In conclusion it appears that in both Duncan Creek and Dry Branch, a combination of factors may have worked to slow the return of the streams to pre-disturbance conditions as indicated by the control streams. Due to the nature of the watershed disturbance caused by strip mining, the habitat recovery was lengthy. This, combined with the lack of good colonization sources may account for the reduced numbers of taxa. Factors which may act to suppress population numbers are not obvious from the present research. There may be water quality or discharge changes which affect the insect populations but are not apparent without more detailed study. It is also possible that these differences are an artifact of sampling or just represent a cyclic low point in population numbers. These questions must be left for future research. Although this study does not "prove" that the observed differences are due to mining effects, the results do suggest that the influences of disturbances the magnitude of strip mining may disrupt normal watershed processes for many years. Of particular concern is the possibility of disturbing such extensive areas that the numbers of taxa, particularly rare species, will never recover due to lack of recolonizers and that stream productivity may continue to be low for at least as long as twenty-five years.

LITERATURE CITED

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Allen, R. K., and R. F. Edmunds. 1962. A revision of the genus Ephemerella (Ephemeroptera: Ephemerellidae). IV. The subgenus Danella. J. Kans. Entomol. Soc. 35:333-338.

__________. 1963. A revision of the genus Ephemerella (Ephemeroptera: Ephemerellidae). VII. The subgenus Eurylophella. Can. Entomol. 95:597-623.

__________. 1965. A revision of the genus Ephemerella (Ephemeroptera: Ephemerellidae). VIII. The subgenus Ephemerella in North America. Misc. Publ. Entomol. Soc. Amer. 4:243-282.

American Public Health Association. 1976. Standard Methods for the Examination of Water and Wastewater. Publ. by APHA, Washington, D.C. 1193 pp.

Avery, G. G., and E. T. Luther. 1970. Mineral resources summary of the Norma Quadrangle, Tennessee. State of Tenn. Dept. of Cons., Division of Geology. 18 pp.

Barton, B. A. 1976. Short-term effects of highway construction on the limnology of a small stream in southern Ontario. Freshwater Biology 7:99-108.

Beck, W. M. 1977. Environmental requirements and pollution tolerance of common freshwater Chironomidae. EPA-600/4-77-024. Environmental Monitoring and Support Lab. Office of Res. and Dev. USEPA. Cincinnati, Ohio. 261 pp.

Bell, H. L. 1971. Effect of low pH on the survival and emergence of aquatic insects. Water Research 5:313-319.

Boccardy, J. A., and W. M. Spaulding, Jr. 1968. Effects of surface mining on fish and wildlife in Appalachia. Bureau of Sport Fisheries and Wildlife Resource Publ. #65. Washington, D.C. 20 pp.

Bohm, R. A., S. L. Carroll, R. A. Minear, J. R. Moore, J. H. Rule, R. E. Shrieves, W. T. Snyder, B. A. Tschantz, and G. A. Vaughn. 1974. Appalachian Resources Project. Progress Report on NSF/RANN funded research related to environmental and economic aspects of coal production. Univ. of Tenn. Env. Center, Knoxville, Tenn. 171 pp.

Branson, B. A., and D. L. Batch. 1972. Effects of strip mining on small-stream fishes in East-Central Kentucky. Proc. Biol. Soc. Wash. 84(59):507-518.

Brown, H. P. 1976. Aquatic Dryopoid beetles (Coleoptera) of the United States. 18050 ELD04/72. Environmental Monitoring and Support Lab. Office of Res. and Dev. USEPA. Cincinnati, Ohio. 82 pp.

Cairns, J., Jr., J. S. Crossman, K. L. Dickson, and E. E. Herricks. 1971. The recovery of damaged streams. ASB Bulletin 18(3):78-106.

Carter, J. 1964. Stream bottom fauna. In Collier, et al. (eds.), Influence of strip-mining on the hydrologic environment of parts of Beaver Creek Basin. U.S. Geol. Surv. Prof. Papers 427 B.

Chutter, F. M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia 34:57-76.

Collier, C. R., R. J. Pickering, and J. J. Musser. 1964. Influences of strip mining on the hydrologic environment of parts of Beaver Creek Basin, Kentucky, 1955-1959. U.S. Geol. Surv. Prof. Papers 427 C.

__________. 1970. Hydrologic influences of strip mining, influences of strip mining on the hydrologic environment of parts of Beaver Creek Basin, Kentucky, 1955-1966. U.S. Geol. Surv. Prof. Papers 427 C.

Curtis, W. R. 1972a. Chemical changes in streamflow following surface mining in eastern Kentucky. Fourth Symposium on Coal Mine Drainage Research. Mellon Institute, Pittsburgh, Pa. pp. 13-31.

__________. 1972b. Strip-mining increases flood potential of mountain watersheds. Proc. Nat. Symp. on Watersheds in Transition. Am. Water Res. Assoc. and Colo. State Univ.

__________. 1977. Hydrologic aspects of surface mining in the east. Proc. of the Soc. American Foresters.

Cummins, K. W. 1973. Trophic relations of aquatic insects. Annual Review of Entomology. Annual Reviews, Inc., Palo Alto, Ca. pp. 183-206.

Dills, G. and D. T. Rogers. 1974. Macroinvertebrate community structure as an indicator of acid mine pollution. Environ. Pollut. 6:239-262.

Dimond, J. B. 1967. Evidence that drift of stream benthos is density related. Ecol. 48:855-857.

Edmunds, G. F., S. L. Jensen, and L. Berner. 1976. The Mayflies of North and Central America. University of Minnesota Press, Minneapolis. 330 pp.

Energy Res. and Devel. Admin. 1977. Proceedings of the public meeting to review the status of the inexhaustible energy resources study. Washington, D.C. n.p.

Environmental Protection Agency. 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. EPA-670/4-73-001. Office of Res. and Dev. USEPA.

Fiance, S. B. 1977. The genera of eastern North American Chloroperlidae (Plecoptera). Key to larval stages. Psyche 83(3-4): 308-316.

Flint, O. S. 1960. Taxonomy and biology of nearctic Limnephilid larvae (Trichoptera), with special reference to species in eastern U.S. Entomologica Americana 40:1-119.

__________. 1962. Larvae of the caddis fly genus Rhyacophila in eastern North America (Trichoptera: Rhyacophilidae). Proceedings of the U.S. National Museum 113:465-493.

Flint, O. S., and G. B. Wiggins. 1961. Records and descriptions of North American species in the genus Lepidostoma, with a revision of the Vernalis group (Trichoptera: Lepidistomatidae). Can. Ent. 93(4):279-297.

Frison, T. H. 1942. Studies of North American Plecoptera with special reference to the fauna of Illinois. Illinois Natural History Survey, 22, article 2:235-355.

Gaufin, A. R., E. K. Harris, and H. T. Walter. 1956. A statistical evaluation of stream bottom sampling data obtained from three standard samplers. Ecol. 37(4):643-648.

Green, R. H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. John Wiley and Sons, Toronto. 257 pp.

Harris, T. L. and T. M. Lawrence. 1978. Environmental requirements and pollution tolerance of Trichoptera. EPA-600/4-78-063. Env. Monitoring and Support Lab. Office Res. and Dev. USEPA. Cincinnati, Ohio. 310 pp.

Hensley, J. P. 1970. Stream bottom fauna. In Collier, et al. (eds.), Influence of stripmining on the hydrologic environment of parts of Beaver Creek Basin. U.S. Geol. Surv. Prof. Papers. 427 C.

Herricks, E. E. and J. Cairns, Jr. 1974. Rehabilitation of streams receiving acid mine drainage. Va. Water Resources Research Center, Bulletin #66. VPI-SU, Blacksburg, Va. 284 pp.

Hilsenhoff, W. L. 1975. Aquatic Insects of Wisconsin. Technical Bulletin #89. Dept. of Nat. Resources. Madison, Wisconsin. pp. 42-52.

__________. 1977. Use of arthropods to evaluate water quality of streams. Technical Bulletin #100. Dept. of Nat. Resources, Madison, Wisc.

Hitchcock, G. W. 1974. Guide to the insects of Connecticut. Dept. of Env. Protection. State Geol. and Nat. Hist. Surv. of Conn. Bulletin #107. 262 pp.

Hubbard, M. D. and W. L. Peters. 1978. Environmental requirements and pollution tolerance of Ephemeroptera. EPA-600/4-78-061. Environmental Monitoring and Support Laboratory. USEPA. Cincinnati, Ohio. 461 pp.

Hynes, H.B.N. 1970. The Ecology of Running Water. Univ. of Toronto Press. Toronto. 555 pp.

Kaesler, R. L. 1978. The use of cluster analysis in the assessment of hazardous material. Am. Midl. Nat. 92:93-114.

Larimore, R. W., W. F. Childers, and C. Heckrotte. Destruction and re-establishment of stream fish and invertebrates affected by drought. Trans. Am. Fish. Soc. 88:261-285.

Leamon, A. R. and Maher, S. W. 1974. Coal Mining in Tennessee (as of November 1974). Information Circular #17. State of Tenn. Div. of Geol., Dept. of Cons. 32 pp.

Luedtke, R. J., and M. A. Brusven. 1976. Effects of sand sedimentation on colonization of stream insects. Jour. of the Fish. Res. Bd. of Can. 33(9):1881-1886.

Luther, E. T. 1967. Geologic map and mineral resources summary for the Block Quadrangle, Tennessee. State of Tenn. Dept. of Cons., Div. of Geol. 85 pp.

Luther, E. T. and G. G. Avery. 1970. Geologic map of the Norma Quadrangle, Tennessee. State of Tenn. Dept. of Cons., Div. of Geol.

Merrit, R. W. and K. W. Cummins. 1978. An Introduction to the Aquatic Insects of North America. Kendall/Hunt Publ. Co., Dubuque, Iowa. 441 pp.

Minear, R. A., B. A. Tschantz, J. H. Rule, G. L. Vaughan, D. E. Overton, and G. Briggs. 1976. Environmental aspects of coal production in the Appalachian region. Appalachian Resources Project Progress Report. Univ. of Tenn. Environ. Center, Knoxville, Tenn. Prep. for ERDA under contract #E-(40-1)-4946. n.p.

__________. 1977. Environmental aspects of coal production in the Appalachian region. Appalachian Resources Project Progress Report. Univ. of Tenn. Environ. Center, Knoxville, Tenn. Prep. for ERDA under contract #E-(40-1)-4946. n.p.

__________. 1978. Environmental aspects of coal production in the Appalachian region. Appalachian Resources Project Progress Report. Univ. of Tenn. Environ. Center, Knoxville, Tenn. Prep. for USDOE under contract #EY-76-S-05-4946. n.p.

Minear, R. A., B. A. Tschantz, G. L. Vaughan, and Donald E. Overton. 1979. Environmental aspects of coal production in the Appalachian region. Appalachian Resources Project Report. Prep. for USDOE under contract #EY-76-S-05-4946. Univ. of Tenn. Env. Center, Knoxville, Tenn. n.p.

__________. 1980. Environmental aspects of coal production in the Appalachian region. Appalachian Resources Project Report. Prep. for USDOE under contract #EY-76-S-05-4946. Univ. of Tenn. Env. Center, Knoxville, Tenn. n.p.

Minshall, G. W. 1967. The role of allocthanous detritus in the trophic structure of a woodland springbrook community. Ecol. 48(1):139-149.

Moffet, J. W. 1936. A quantitative study of the bottom fauna in some Utah streams variously affected by erosion. Bull. Univ. Utah Biol. Ser. 26(9):1-33.

Morgan, J. D. 1976. Availability of conventional energy resources materials--coal. National Technical Information Service. PB-255 798. U.S. Dept. of Commerce, Bureau of Mines.

Morihara, D. K. and W. P. McCafferty. 1979. The Baetis larvae of North America (Ephemeroptera:Baetidae). Trans. of the Am. Ent. Soc. 105:139-221.

Needham, P. R., and R. L. Usinger. 1956. Variability in the macrofauna of single riffle in Prosser Creek, California, as indicated by the Surber Sampler. Hilgardia 24:383-409.

Neel, J. K., Sr. 1973. Biotic character as related to stream mineral content. Trans. Amer. Micros. Soc. 92(3):404-415.

Office of Technology Assessment. 1979. The direct use of coal. Congress of the United States. Washington, D.C. n.p.

Ricker, W. E. 1952. Systematic studies in Plecoptera. Indiana University Publications, Science Series No. 18. Indiana University Press, Bloomington, Indiana. 200 pp.

Roback, S. S., and J. W. Richardson. 1969. The effects of acid drainage on aquatic insects. Proc. Acad. Nat. Sci. Phil. 121:81-107.

Rose, R. R. 1975. Aspects of water quality and their relationship to hydrology in coal mined drainage basins in the Cumberland Mountains. Master's thesis, The University of Tennessee, Knoxville.

Ross, H. H. 1944. The caddisflies or Trichoptera of Illinois. Ill. Nat. Hist. Sur. 326 pp.

Rotty, R. A., and A. M. Weinberg. 1976. How long is coal's future? Institute for energy analysis. IEA(M)76-1. Oak Ridge Assoc. Univ., Oak Ridge, Tenn. 24 pp.

Schmid, F. 1970. Le genre Rhyacophila et la famile of Rhyacophilidae (Trichoptera). Mem. Soc. Ent. Canada 66:1-230.

Schuster, G. A. and D. A. Etnier. 1978. A manual for the identification of the larvae of the caddisfly genera Hydropsyche Pictet and Symphitopsyche Ulmer in eastern and central North America (Trichoptera:Hydropsychidae). EPA-600/4-78-060. USEPA, Cincinnati, Ohio. 126 pp.

Shannon, C. E., and W. Weaver. 1963. The Mathematical Theory of Communication. Univ. of Ill. Press, Urbana.

Sokal, R. R., and F. J. Rolf. 1969. Biometry. W. H. Freeman and Company. 776 pp.

Southwood, T.R.E. 1978. Ecological Methods with Particular Reference to the Study of Insect Populations. Halstead Press, John Wiley and Sons, Inc. 523 pp.

Statler, A. T. 1970. Mineral resources summary of the Duncan Flats Quadrangle, Tennessee. State of Tenn. Dept. of Cons., Div. of Geol. 26 pp.

Statler, A. T. and G. Sykes. 1970. Geologic map of the Duncan Flats Quadrangle, Tennessee. State of Tenn. Dept. of Cons., Div. of Geol.

Surdick, R. F., and A. R. Gaufin. 1978. Environmental requirements and pollution tolerance of Plecoptera. EPA-600/4-78-062. USEPA Environmental Monitoring and Support Lab., Cincinnati, Ohio. 417 pp.

Talak, A. 1977. The recovery of stream benthic insect communities following coal strip mining in the Cumberland Mountains of Tennessee. Master's thesis. The University of Tennessee, Knoxville. 81 pp.

Tanner, J. T. 1978. Guide to the Study of Animal Populations. University of Tennessee Press, Knoxville. 181 pp.

Tarter, D. C. 1976. Limnology in West Virginia: A lecture and laboratory manual. Marshall Univ., West Virginia. 249 pp.

Tolbert, V. R. 1978. Effects of strip mining related disturbance on benthic insect communities of selected streams in the New River Basin of East Tennessee. Ph.D. dissertation. The University of Tennessee, Knoxville. 104 pp.

Townsend, C. R., and A. G. Hildrew. 1976. Field experiments on the drifting, colonization and continuous redistribution of stream benthos. J. Animal Ecol. 45:759-772.

Tung, H. 1975. Impacts of contour coal mining on streamflow, a case study of the New River watershed, Tennessee. Ph.D. dissertation. The University of Tennessee, Knoxville. 138 pp.

TVA. 1977. Response of biological communities of Barkley Reservoir to thermal effluents from Cumberland Steam Plant. Tennessee Valley Authority Division of Environmental Planning. Water Quality and Ecology Branch. pp. 399-484.

Usinger, R. E. (ed.). 1974. The Aquatic Insects of California. Berkeley and Los Angeles. Univ. of Cal. Press. 508 pp.

Vaughan, G. L., A. Talak, and R. J. Anderson. 1978. The chronology and character of recovery of aquatic communities from the effects of strip mining for coal in east Tennessee. Symposium proceedings. Surface Mining and Fish/Wildlife Needs in the Eastern United States. West Virginia U. and the U.S. Dept. of the Int. Fish. and Wildlife Ser.

Vaughan, G. L. 1978. Effects of stripmining on fish and diatoms in streams of the New River drainage basin. Journal of the Tennessee Academy of Science 54(3):110-114.

Waters, T. F. 1964. Recolonization of denuded stream bottom by drift. Trans. Am. Fish. Soc. 93:311-315.

Where We Agree. 1979. Report of the National Coal Policy Project. Center for Strategic and International Studies. Georgetown Univ., Washington, D.C. 39 pp.

Wiggins, G. B. 1977. Larvae of the North American Caddisfly Genera (Trichoptera). Univ. of Toronto Press, Toronto, Can. 401 pp.

Wilhm, J. L., and T. C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience 18(6):477-481.

Williams, N. E., and H.B.N. Hynes. 1976. The recolonization mechanisms of stream benthos. Oikos 27:265-272.

Zar, J. H. 1974. Biostatistical Analysis. Prentice-Hall, Inc. Englewood Cliffs, N.J. 621 pp.

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