3-1977

The Recovery of Stream Benthic Insect Communities Following Coal Strip Mining in the Cumberland Mountains of Tennessee

Anthony Talak Jr.
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Anthony Talak Jr. entitled "The Recovery of Stream Benthic Insect Communities Following Coal Strip Mining in the Cumberland Mountains of Tennessee." 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 Master of Science, with a major in Ecology and Evolutionary Biology.

David A. Etnier, Major Professor

We have read this thesis and recommend its acceptance:

J. Larry Wilson, Gerald S. Uglon

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

THE RECOVERY OF STREAM BENTHIC INSECT COMMUNITIES FOLLOWING COAL STRIP MINING IN THE CUMBERLAND MOUNTAINS OF TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Anthony Talak, Jr.

March 1977

ABSTRACT

The aquatic insect faunas of twenty-three streams in the Cumberland Mountains of Tennessee were investigated. The purpose of the study was to analyze the recovery through time of the aquatic insect faunas of streams polluted by runoff from contour strip mines.

Quantitative determinations of the benthic insect fauna were made using two methods. The first involved removing substrate particles and picking off the insects with forceps. The second was a Surber Sampler type method of placing a screen in the streams and disturbing the substrate upstream of the screen.

Rather than sample one stream over a period of years, simultaneous samples were taken in streams of similar flow and substrate characteristics, both in watersheds which had been disturbed by strip mining activities at various times in the past and in control streams. It was possible in this manner to analyze changes in community structure occuring over a twenty-two-year period following the cessation of strip mining activities.

General recovery trends were analyzed quantitatively by plotting the number of individuals, number of taxa, and a species diversity index against time. It was found that all three parameters decreased after the cessation of mining, reaching a minimum after four to six years. After this time the values began to increase, returning essentially to predisturbance levels after twenty-two years. Qualitative analysis of the insects actually present, however, shows that the structure of the communitywas altered and even after twenty-two years it had not returned

to normal. The change in faunal composition does not appear to be due to acid mine drainage but most probably to the effects of siltation. The role of increased concentrations of dissolved constituents was not evaluated and it is possible some of the effects on the insect faunas are attributable to this factor.

PREFACE

The purpose of this research was to assess the effects of coal surface mining on the aquatic insect faunas of streams. Further aspects of the environmental impact of coal surface mining are being investigated at the University of Tennessee by the departments of Environmental Engineering and Zoology. The purpose from the start has been to establish communication and share expertise between a variety of disciplines on a common problem. Physical and chemical water quality data are being investigated by the Environmental Engineering department in a number of the streams sampled in this research. The effect of strip mining on hydrology in the New River watershed has been studied by the Civil Engineering department. Biologically, in addition to the research performed for this thesis, Diatom populations are being studied as well as the diversity of fish communities. It is hoped that anyone seeking to investigate as fully as possible the environmental impact of coal surface mining will consult these additional sources of information for a truly interdisciplinary view of a multifaceted problem.

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CHAPTER I

INTRODUCTION

Surface mining is probably the oldest form of coal recovery in Tennessee (Boccardy, 1968). It was not until after World War II, however, that this type of mining began to be practiced on a large scale. There are two major types of coal surface mining, area and contour, with the type used depending on the topography of the area to be mined. Area mining, illustrated in Figure 1, is practiced on flat terrain.

A sequential series of parallel trenches is dug down to the coal seam and the overlying material, the overburden, is used to fill in a trench from which the coal has already been extracted (Green, 1969; Grim, 1974). This type of mine is easily and economically reclaimed (Brooks, 1970). The second type of surface mine, illustrated in Figure 2, is contour mining. It is practiced in mountainous areas where, as the name implies, a coal seam is followed around a mountain (Anon., 1973). The overburden is removed and usually pushed down the mountain below the coal outcrop. Since the overburden is commonly removed with explosives, the spoil may be cast a considerable distance down slope. The removal of the overburden forms a flat "bench" from which the coal is removed. This type of mine is more expensive and difficult to reclaim than an area mine. It also has a greater environmental impact, with the overburden of one stripped acre affecting up to four acres on the downhill slope (Brooks, 1970). The contour mine is the type most often encountered in the Cumberland mountains of Tennessee. At the present

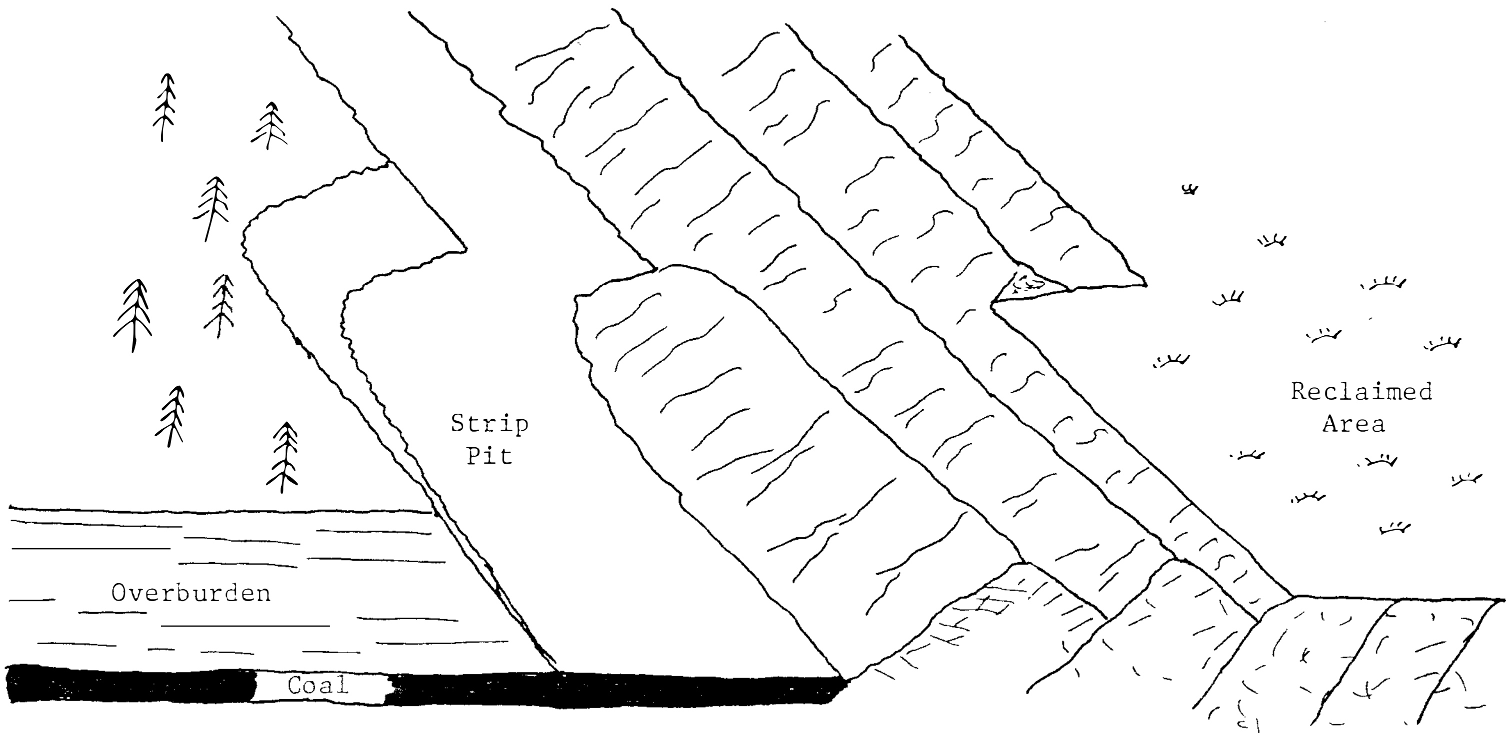

Figure 1. Diagrammatic representation of an area strip mine.

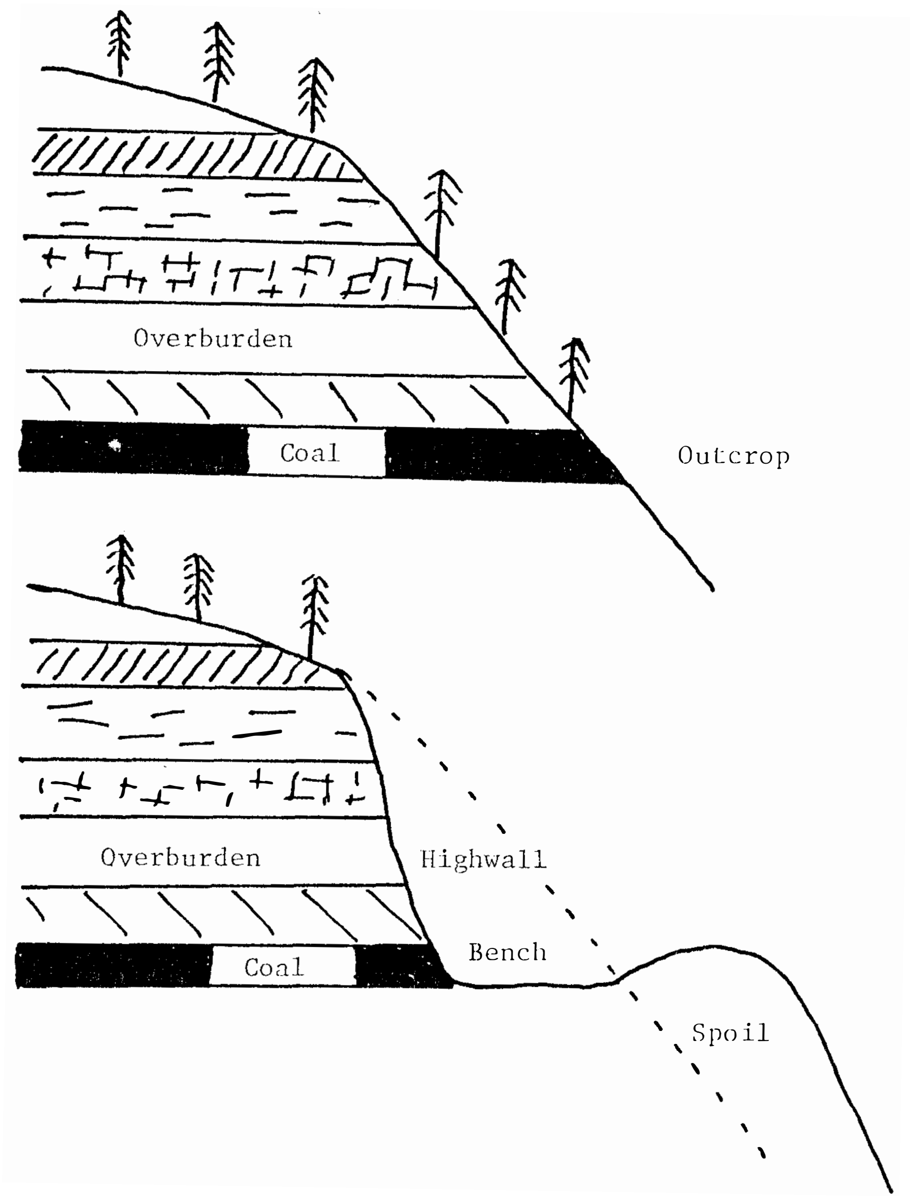

Figure 2. Diagrammatic representation of a typical contour strip mining operation.

time, reclamation is required by state law. Unfortunately establishment of reclamation requirements is a recent phenomenon and over 26,000 acres of land were stripped in Tennessee prior to the enactment of regulatory legislation (Boccardy, 1968). These "orphan" mines remain largely unreclaimed. This study was undertaken to determine how the benthic insect faunas of streams affected by strip mine drainage recover after the cessation of mining activities. The benthic insect fauna was chosen for investigation because benthic organisms are relatively sessile and easy to sample, and they have long life cycles which tend to indicate past as well as present environmental conditions (Cairns and Dickenson, 1971; Crossman, 1973; Dambach, 1969; Mackenthum, 1966).

CHAPTER II

THE STUDY AREA

The coal fields of Tennessee are part of the Appalachian region, extending from central Pennsylvania into Alabama (see Figure 3). The coal deposits extend through the central portion of the state in a relatively narrow strip running in a northeast to southwest direction. The study was conducted in the Cumberland Mountains; specifically in Anderson, Campbell, Morgan and Scott counties, an area which produces approximately 70 % of the coal mined in Tennessee (Larson, 1976). The area is in the northeast portion of the Tennessee Coal Belt bounded approximately by U.S. 27 on the west, Tennessee 63 on the north, Tennessee 116 on the south and U.S. 25W on the east.

With a few minor exceptions, the area is sparsely populated and access to many areas is limited. The major portion of the study area drains into the New River. The southwestern portion drains into the Emory River and the most easterly section drains into the Clinch River system. The hydrology and physiography of the New River and Emory River basins have been investigated and are very similar (Anon., 1960; Gairola, 1947; Tung, 1975). Both are characterized by moderate temperatures with an annual average of 55°F, and usually at least 50 inches of rain a year. The extreme relief of the area tends to result in most of the precipitation being rapidly lost as runoff with the consequence that many of the smaller streams tend to cease flowing periodically due to the lack of groundwaterrecharge (Gairola, 1947).

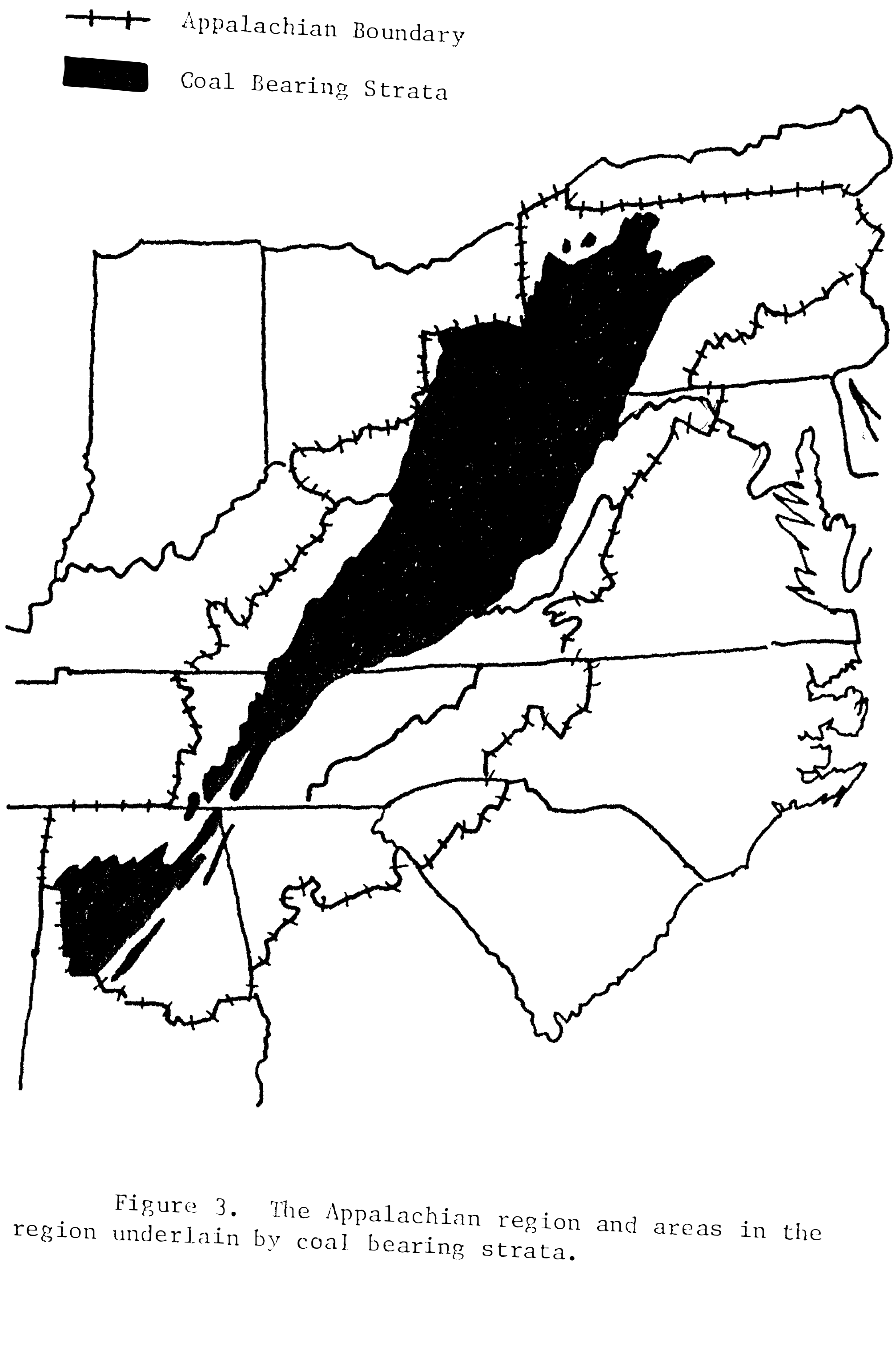

Figure 3. The Appalachian region and areas in the region underlain by coal bearing strata.

This area has borne the brunt of strip mining activities in the state with 2,269 acres having been mined in Anderson county, 5,123 acres in Campbell county, 3,211 acres in Morgan county, and 5,594 acres in Scott county (Johnson and Luther, 1972). Surface disturbance is so widespread in fact that one of the major problems initially encountered was the scarcity of unaffected streams to use as controls.

The coal seams of importance in the study area are contained in strata of the middle Pennsylvanian geologic age. The rocks are predominantly sandstone, shale, and siltstone, with coal constituting a small percentage of the total (Luther, 1960). The middle Pennsylvanian sequence has been divided into a number of formations with the "Redoak Mountain" and "Graves Gap" formations being those most commonly encountered in the study area. Figure 4 shows the coal seams of importance in the study area and their relative positions in these formations. In the Graves Gap formation, Lower Pioneer coal is mined in Campbell county and the Windrock seam at the top of the formation is mined in Anderson, Campbell, and Scott counties. The Redoak Mountain formation contains the most widely exploited coal seams in the area. The Red Ash seam is mined in Campbell and Scott counties; Walnut Mountain coal is mined in Anderson, Morgan and Scott counties; and Peewee and Big Mary coal are mined in all four counties of the study area (Anon., 1972; Johnson and Luther, 1972).

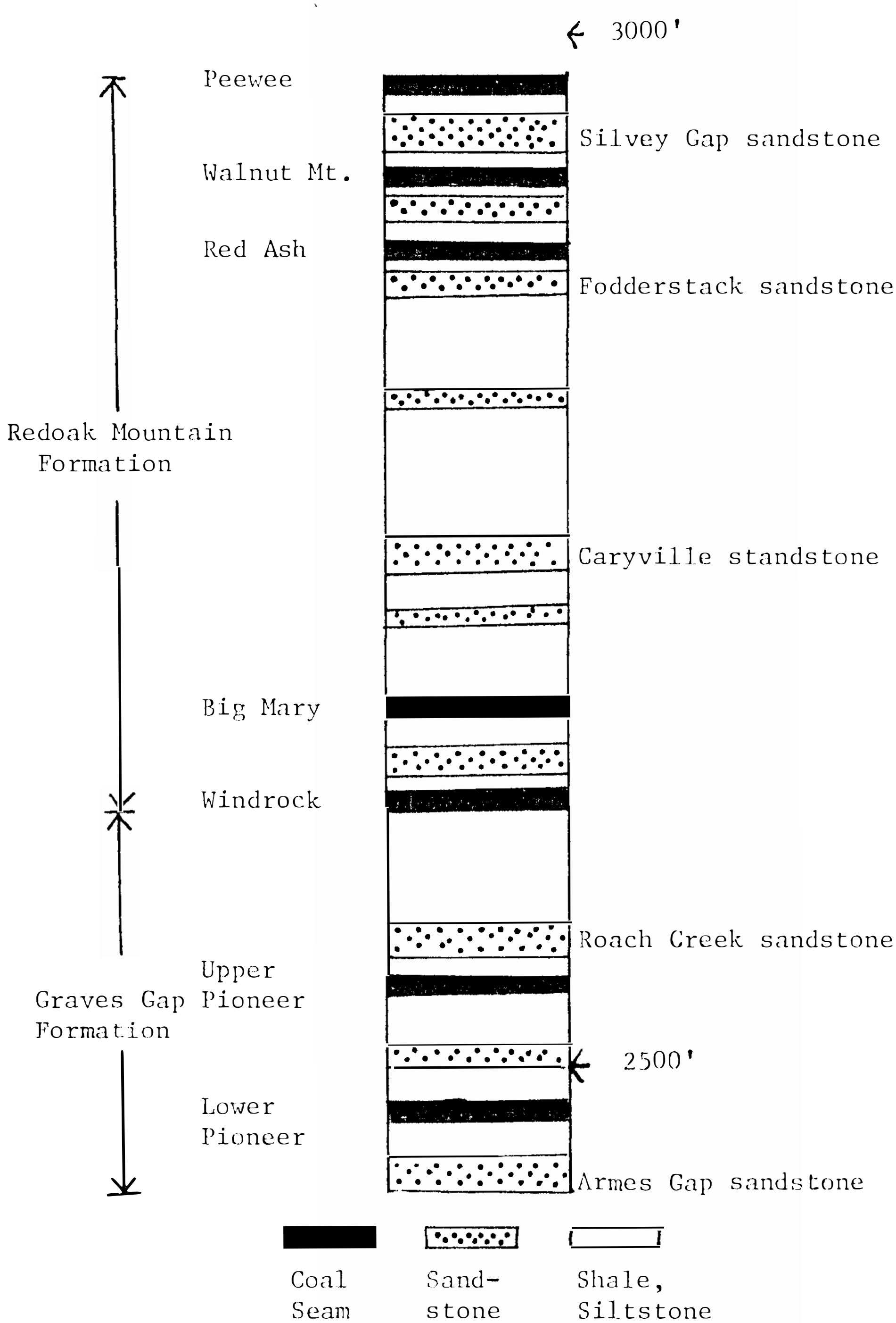

Figure 4. Generalized stratiographic sequence of the Pennsylvanian coal bearing strata of the study area.

CHAPTER III

LITERATURE REVIEW

A. ACID MINE DRAINAGE

Introduction

Of all the adverse effects on aquatic ecosystems brought about by coal mining, the one long considered most damaging has been acid mine drainage (Anon., 1969a). Acid mine drainage affects over 5,000 miles of the 10,000 miles of streams affected by all forms of mine drainage (Kinney, 1964). The number of miles and locations of the streams affected by acid mine drainage are given in Table 1 (Anon., 1969b). It is apparent from these data that the incidence of occurrence of acid mine drainage is greatest in the northeastern section of the Appalachian region and decreases as one proceeds to the southwest. The underlying mechanisms of acid mine drainage formation are complex and not completely understood (Hill, 1968). The following outline is often encountered, however, and generally depicts the process as it is usually thought to take place.

Chemistry of Formation

Pyritic materials, primarily iron disulfide, are often associated with the coal seam or the adjacent geological formations (Anon., 1969b). The removal of the overburden may expose these materials which will be oxidized as shown in equations 1 and 2 with the consequent production of ferrous iron and sulfuric acid (Barnes, 1968; Hill, 1968; Grim, 1974).

TABLE 1

MILES AND DISTRIBUTION OF STREAMS AFFECTED BY MINE DRAINAGE
FOR THE APPALACHIAN REGION

Drainage	Area (sq. mi.)	Stream Miles[1]	Miles of Streams Affected: Inter.	Miles of Streams Affected: Mine Drainage[2] Contin.	Miles of Streams Affected: Acid Mine Drainage[3]	Proportion of Area Streams Affected: MD (%)	Proportion of Area Streams Affected: AMD (%)
Anthracite Region	4,200	6,300	350	260	567	9.6	9.0
Tioga	2,800	4,200	20	35	55	1.3	1.3
West Branch Susquehanna	6,900	10,350	600	540	1,035	11.0	10.0
Juniata	3,400	5,100	20	60	82	1.6	1.6
North Branch Potomac	2,200	3,300	40	130	172	5.2	5.2
Allegheny	11,730	17,590	87	979	1,055	6.1	6.0
Monongahela	7,100	11,100	289	1,382	1,665	15.1	15.0
Beaver	1,500	2,250	40	68	54	4.8	2.4
Muskingum	4,340	6,510	108	414	260	8.0	4.0
Hocking	1,200	1,800	141	223	90	20.2	5.0
Little Kanawha	2,300	3,450	25	5	-	0.9	-
Kanawha	12,300	18,450	544	859	148	7.6	0.8
Scioto	2,300	3,450	8	-	-	0.2	-
Guyandotte	1,670	2,505	11	288	70	11.9	2.8
Big Sandy	4,300	6,450	442	58	-	7.8	-
Ohio and Minor Tributaries	12,600	18,900	166	1,164	321	7.0	1.7
Kentucky	4,500	6,750	430	65	14	7.3	0.2
Cumberland	10,850	16,275	305	205	65	3.1	0.4
Tennessee-Black Warrior	28,000	42,000	-	-	84	0.4	0.2
Totals		186,730	3,656	6,705	5,736		

TABLE 1 (Cont'd)

Source: Appendix C, Anon., 1969b, Stream Pollution by Coal Mine Drainage in Appalachia. U. S. Dept. of Interior, Washington, D.C.

[1]The total stream miles in these areas was estimated using 1.5 miles/sq. mile drainage density.

[2]"Inter." is Intermittently or Potentially; "Contin." is Continuously or Significantly; Mine Drainage is subsequently abbreviated MD.

[3]Estimate based on large scale maps in Appendix C, Anon., 1969b. Acid Mine Drainage is subsequently abbreviated AMD.

The reaction then proceeds to form ferric hydroxide and more acid as shown in equations 3 and 4. Ferric hydroxide is also known as yellowboy, and is the red-yellow precipitate responsible for the color of many stream beds in coal mining regions (Goldberg, 1972; Anon., 1971).

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4 \quad (1)$$

$$FeS_2 + 14Fe^{+3} + 8H_2O \rightarrow 15Fe^{+2} + 2SO_2{}^{-2} + 16H^+ \quad (2)$$

$$4FeSO_1 + 2O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O \quad (3)$$

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4 \quad (4)$$

Factors Affecting Formation

The reactions just described can produce a water with a ph as low as two depending on a number of factors such as: The amount and specific form of the pyrites in the coal and overburden, the time of contact between the water and the pyrite, the amount of water present, and the particular makeup of the overburden (Mansfield, 1965; Hill, 1968; Morth, 1972). These factors are further discussed by Grim (1974) who says that crystalline forms of pyritic materials are less subject to weathering and oxidation than are amorphic forms and hence are less likely to cause acid problems. He also discusses the importance of contact times between the pyrites and atmospheric oxygen, and the importance of alkaline materials in the overburden as a factor decreasing the danger of acid mine drainage.

Sources and Extent of Acid Mine Drainage

To date the bulk of the research done on the impact of the coal mining industry on water quality and aquatic ecosystems has dealt with

the problem of acid mine drainage. It can not be denied that acid mine drainage is a serious pollution problem in the Appalachian region. It was not considered a serious factor in the present investigation, however, because it is more of a problem in deep mining than it is in strip mining. As shown in Table 2, in the Appalachian region in general, 71.3% of the acid mine drainage is estimated to originate in underground mines. Surface mines account for 12%, combined surface and underground mines 9.2%, and other sources such as processing plants 7.5% (Anon., 1969a). Inactive mines are the source of 78% of the region's acid mine drainage, with inactive underground mines accounting for 66% of that amount. In the final analysis, more than 85% of the acid mine drainage from active mines in Appalachia results from discharge from underground mines (Anon., 1969A). This data is for the entire Appalachian region. In point of fact, due to lower sulfur concentrations in the coal and overburden in our area, and the greater proportion of alkaline materials in the Pennsylvanian strata of Tennessee, acid mine drainage is not considered a serious problem in the state (Elmore, 1961; Anon., 1968; Anon., 1969a). The data in Table 2 support this conclusion as does the research of Curtis (1972) and Larson et al. (1975) who found that both the ph and alkalinity of streams in this area often actually increase after surface mining. This behavior is explained by the fact that in undisturbed watersheds runoff acquires a very small mineral load and hence has a low alkalinity. For this reason ph is controlled by dissolved carbon dioxide from the atmosphere and is relatively low (Larson, 1975). After mining the alkalinity increases due to the increased leaching of previously inaccessible materials in the disturbed

TABLE 2

PERCENTAGE DISTRIBUTION OF THE NUMBER, SOURCES AND PROPORTION OF AMD BY TYPE OF MINE

	Type of Mines			Other	Sub-
	Underground	Surface	Combination	Sources	totals
Number of Sources					
Active Mines	5.0	1.4	0.4	0.5	7.3
Inactive Mines	53.0	27.0	8.4	4.3	92.7
Totals	58.0	28.4	8.8	4.8	100.0
Amount of Acid Drainage					
Active Mines	18.8	0.9	1.9	0.4	22.0
Inactive Mines	52.5	11.1	7.3	7.1	78.0
Totals	71.3	12.0	9.2	7.5	100.0

Source: Anon., 1969b, Stream Pollution by Coal Mine Drainage in Appalachia. U. S. Dept. of Interior, Washington, D.C.

surface areas of the watershed. This increased alkalinity results in a greater acid neutralizing capacity and a higher ph (Upham, 1975).

Biological Effects

Studies of the effects of acid mine drainage on aquatic ecosystems can be divided into two general categories, effects on lake systems and effects on stream systems. Lakes are most often affected in situations involving area strip mines. This will be apparent if one reexamines Figure 1 (page 2) and considers the topography which would result if the area is not reclaimed. The last pit often fills with water, becoming a "strip pit" lake. Contour strip mining (Figure 2, page 3) on the other hand most often results in pollution of stream systems.

Lake ecosystems. Smith and Frey (1971) give an excellent review of the literature on the effects of acid mine drainage on lake ecosystems. Many studies of lakes such as those of Bell (1956) and Stockinger (1960) deal with the reactions of specific taxa and are qualitative in nature. An ecosystem approach to assessing the effects of acid mine drainage was taken by Dinsmore (1958), Heaton (1950), Campbell et al. (1965a, 1965b) and Crawford (1942) who all found an increase in the complexity of the community and a decrease in acidity associated with aging. This community response pattern is similar to that found by Keup (1966) and Bartsch (1959) for systems recovering from organic pollution where an increase in complexity occured downstream of the area degraded by organic pollution. Lind and Campbell (1970) found that this change in community structure is not reflected in "community metabolism," i.e., community respiration was similar in acid

and alkaline strip mine lakes and the P/R ratio of each lake fluctuated around unity even though the diversity was inversely related to the acidity.

Stream ecosystems. Studies on the effects of acid mine drainage on stream ecosystems are numerous and their results are often conflicting. Parsons (1956) in a stream study in Missouri found a pattern of linear succession downstream of an acid source which suggested the type of recovery found in systems recovering from organic pollution (Bartsch, 1959; Keup, 1966). The same general pattern of reduction in the benthic insect fauna is described by Riley (1960), Patrick et al. (1956), Parsons (1952), Roback and Richardson (1969), Cairns and Herricks (1974), Dills and Rogers (1974), and Oliff (1963).

It is interesting to note, however, that although the same general pattern, a reduction in community diversity, is common to all these investigations, the actual species of the community most seriously affected vary quite widely. Roback and Richardson (1969) found Odonata, Plecoptera, and Ephemoptera completely eliminated. Dills and Rogers (1974) found these orders present but in reduced numbers while chironomids and megalopterans dominated the community. Butler et al. (1973) found the odonate Boyeria vinosa and the megalopteran Nigronia fasciata tolerant of low ph. Oliff (1963) found all insects reduced equally with none apparently more tolerant than others, while Parsons (1956) found that an insect community composed of the dipterans Probezzia sp., Spaniotoma sp., and the Megalopteran Sialis sp. was well adapted to an acid mine drainage environment. Bick, Hornuff, and

Lambremont (1953) found mayflies "numerous both as to number of species and number of individuals," as well as numbers of odonates and trichopterans. A classification of community structure in streams of various ranges of acid pollution is given in Table 3 (Anon., 1969) although in light of the conflicting results just examined and the fact that no research is cited to support the table, it is hard to assess its usefulness.

There is an obvious lack of agreement in the ecological studies just cited. Those communities observed fail to coincide with those which would be predicted on the basis of such laboratory studies on the effects of ph on aquatic insects as those of Bell and Nebeker (1969) and Butler et al. (1973). These two facts indicate that ph in and of itself is not the dominant factor in determining community structure it is commonly assumed to be.

Dills and Rogers (1974) found that increased ionic content accompanied decreased ph and lower species diversity indices. Although the relationships between ph and metal solubilities are complex, they postulated the ionic species present may exert a greater influence on community structure than the actual ph. This conclusion is supported to some extent by Warnick and Bell (1969) who found heavy metals to be the most important parameter influencing mortality in different species of aquatic insects. They found that the insects absorbed significant concentrations of the metal ions from solution. Dill and Rogers (1974) found that mine drainage which had been acid neutralized but which still had a high ionic concentration could cause a reduction in species diversity of 68%.

TABLE 3

PH RANGE, REPRESENTATIVE COMMUNITIES AND BIOLOGICAL STATUS OF COMMUNITY COMPONENTS IN ACIDIC AQUATIC ENVIRONMENTS

ph Ranges	Warm Water Species	Cold Water Species	Benthos	Algae
6.5-7.0	Full fish production	Full fish production	Relatively normal,[5]	Essentially normal[5]
6.0-6.5	Maintenance but no growth[2]	Full fish production[1]		
5.5-6.0	Maintenance but no carryover[3]	Maintenance and growth[2]	Diverse fauna of benthic organisms; number of different species. Blackflies, mayflies and stoneflies are present in numbers.	Diatoms, flagellates, and green algae are common; <u>Oscillatoria</u> may be found, only blue-green algae commonly occurring at ph lower than 7.0
5.0-5.5	No viable fishery	Maintenance but no carryover[3]		
4.5-5.0	No viable fishery	No viable fishery[4]	Little change	Diatoms may be dominant algae; a decrease in number of different taxa
4.0-4.5	No viable fishery	No viable fishery	Caddisflies and Odonata are present; Tendipedids and Chrionomids are (cont.)	Number of different taxa decreases greatly; diatoms may be dominant algae, flora (cont.)

TABLE 3 (Cont'd)

ph Ranges	Warm Water Species	Cold Water Species	Benthos	Algae
			dominant	little changed from that of lower ph levels; microcrustaceans may be common
3.5-4.0	No viable fishery	No viable fishery	Little change	Little change
Below 3.5	No viable fishery	No viable fishery	Tendipedids, chironomids, ceratopogonids, and Sialis are common	Often only 2.3 algal species found; Euglena mutabilis and Eunotia exigura often found in large numbers; microcrustaceans may be common

Source: Anon., 1969a. Acid Mine Drainage in Appalachia. Report of the Appalachian Regional Commission. Document No. 91-180, 91st Congress, First Session, Washington D.C.

[1]"Viable fishery" - capability of a stream to reproduce species.

[2]"Maintenance and growth" - prevention of reproduction but existing on stocked fish populations that survive and grow over the entire year.

[3]"Maintenance but no carryover" - fish maintenance by stocking but no carryover.

[4]"No viable fishery" - no vertebrate life survives.

[5]"Normal" - a large number of species, each species in relatively low numbers.

In light of these facts, it would seem that the inverse relationship between ph and community diversity is to some extent a spurious one. Granted that it is difficult to separate the direct effects of high hydrogen ion concentration from the effects of various heavy metals which may have different solubilities and toxicities at various ph levels, it must be remembered that most studies assume ph is the controlling factor in community structure with little or no proof. Alone, ph readings reveal little of the actual chemistry of a water, and so it is possible for waters with the same ph to have vastly different compositions depending on geologic characteristics of their watersheds. This would do much to explain the disparity in community structure revealed in the existing literature for waters of similar ph in different geologic environments.

B. EROSION AND SILTATION

Introduction

While acid mine drainage is largely a result of underground mining, stream siltation is the major problem associated with surface mining, particularly contour mining (Greene, 1975). The spoil banks themselves are the major sources of erodable materials although access, haulage, and prospecting roads may contribute as much sediment as the spoil banks in some instances (Anon., 1967). As the amount of rainfall and slope steepness increases, erosion and stream sedimentation become more serious problems (Goldberg, 1972). In a study in Kentucky where both rainfall and slope steepness are high, it was found that spoil banks produced over a thousand times the amount of sediment of an

undisturbed forest (Anon., 1967). Although extensive data are not yet available for Tennessee, the similarity in topography would indicate erosional losses are comparable to those occurring in Kentucky. While the control of surface runoff is an indispensible prerequisite to erosion control it was found that 98% of the surface mined lands in Appalachia lack adequate runoff control, and landslides and erosion are common even after reclamation (Anon., 1968). The effects of sediment on aquatic systems include nonbiotic effects, primarily a reduction in the storm carrying capacity of streams in strip areas (Goldberg, 1972) as well as effects on the stream biota to be discussed shortly.

Factors Influencing Erosion and Sediment Load

Greene (1975) lists a number of factors affecting erosion in conjunction with surface mining. Among these are (1) soil type, (2) degree of slope, (3) length of slope, (4) amount of rainfall, and (5) climate. To these one would have to add the extent of disturbance of the watershed to assess the total erosional potential of a mining operation. Factors 1, 4 and 5 were considered to be the same in each of the watersheds sampled in this investigation.

In most cases, factor 3, the length of slope, increases as factor 2, the degree of slope, increases. This is due to slides of unstable spoil material placed on the steep outslopes. The degree of slope is relatively constant in the mined watersheds, however (Larson, 1975), and no effort was made to separate the watersheds on this basis although the extent of disturbance had to be considered to assure comparability of watersheds. Most watersheds where more than one seam

was mined were excluded from the investigation. The watersheds of Jake Branch, Belchers Creek, and Sugarcamp Creek all had two seams mined but the extent of mining of the second seam was not considered sufficient in these three cases to cause the streams to be excluded from the study.

Sources and Extent of Sedimentation

According to Curtis (1973), the three major sources of sediment associated with strip mining activities are spoil slides, haul roads, and the mined area itself. The total sediment load may be enormous. One study (Anon., 1967) found the sediment load of strip mined watersheds was increased 1,000 times over that of unmined forested watersheds. Branson and Batch (1972) indicated that siltation may be increased 15 to 30 times over that present in unaffected streams.

The importance of spoil slides is emphasized by Plass (1967) who found that they had occurred on 12% of the outslopes investigated in eastern Kentucky. Quantitative data are not available for Tennessee but slides, even on reclaimed areas, are common and probably occur with similar regularity.

Haul roads are a factor in erosion and sedimentation almost as important as the stripped areas themselves (Anon., 1967). Curtis (1973) and Weigle (1965) also discuss the importance of improperly constructed and maintained haul roads as a major source of sediment.

The rate of sediment loss from the mined area proper has been quantified in several studies. Curtis (1973), in a study in eastern Kentucky watersheds similar to those of the present study area, found

an erosion rate of 5.9 tons per acre per year in a watershed where disturbance was limited to 6.4% of the total watershed area. This contrasts with a rate of .7 tons per acre per year in an unmined control watershed. The amount of sediments retained in and recovered from stream weirs in this study ranged from 4,516 to 41,707 cubic feet per year per square mile of watershed. It must be pointed out, however, that these figures only represent the sediment trapped, which is some undetermined fraction of the total sediment transported to the receiving stream.

In a study on the impacts of strip mining on water quality in the New River study area (Larson et al., 1976), the University of Tennessee Civil Engineering department observed behavior similar to that found by Curtis (1973). In undisturbed watersheds suspended solids consistently remained below 25 mg/l and total solids did not exceed 50 mg/l. In addition, there was very little variation during the study period regardless of precipitation or season. In disturbed watersheds however, suspended solids regularly exceeded 1,000 mg/l and occasionally exceeded 10,000 mg/l. Although the suspended solids measurements are similar to those reported for Kentucky the erosion rates are vastly different, with the New River study indicating 150 cubic feet of sediment annually per square mile of watershed (2.5 tons per acre per year). The wide discrepancy between these values and those of Curtis of Kentucky (5.9 tons per acre per year) undoubtedly reflects the difference in reclamation requirements of the two states. It must be remembered however that all the streams in this study, with the exception of Bills Branch, were mined prior to the enactment of present reclamation requirements (July 1975) and for this reason the higher sedimentation rates of the

Kentucky study probably approximate more closely the initial conditions in the study streams.

Biological Effects

According to Hynes (1974), there are two major effects of inorganic sediments introduced into aquatic ecosystems. The first is an increase in the turbidity of the water with a consequent reduction in the depth of light penetration. The second is a blanketing effect on the substrate.

The first consequence of a reduction in light penetration is a reduction in autochthanous primary production (Chutter, 1968; Jones, 1966) or in extreme cases a complete elimination of plant and algal growth (Hynes, 1974). Surber (1953) suggested that the destruction of plants is the major adverse effect of pollution with inorganic sediment and that animals are only secondarily eliminated because of lack of food. He failed to take into account however, the importance of allochthanous detritus to the energy budget of many stream systems (Hynes, 1970; Fisher, 1970; Likens et al., 1970; Likens, 1972) which would permit the existence of near normal communities in the complete absence of autochthanous primary production. A second consequence of the increased turbidity is a decrease in the population levels of sight feeding fish (Jones, 1966; Stroud, 1967; Bjorn, 1974), while an increase may occur in the population levels of such fish as carp and catfish which are less dependent on sight for feeding.

The blanketing of the substrate has numerous ramifications. When inorganic solids settle out of a water they smother algal growth, kill rooted plants, alter the nature of the substrate (Hynes, 1974),

and interfer with the hatching and development of fish eggs (Chutter, 1968; Jones, 1966; Stroud, 1967). Tebo (1955) found that one alteration of the substrate was a decrease in stability of the newly deposited silt over the previously existing substrate with the consequence that benthic organisms were more subject to being "decimated by flood waters." Branson and Batch (1972) documented the magnitude of the smothering effect when they found salamanders entombed beneath rocks after sections of a stream bottom receiving strip mine runoff were covered to a depth of two to six inches with clay. Gammon (1970) and Brusven (1974) found that invertebrate drift increases as the concentration of suspended solids in the water increases with the consequence that even in the absence of direct smothering a water high in suspended solids can reduce the fauna of an area of a stream. Streams whose invertebrate faunas have been reduced by smothering and increased drift can be repopulated in three ways; by organisms drifting in from tributaries upstream, by upstream flight and egg deposition by adult organisms, and by upstream movements of the larval organisms themselves (Hynes, 1970). The research of Brusven (1974) indicates that upstream movement of larval organisms is decreased in waters with high sediment loads, thus restricting one method of recolonization. Although not much research has been done on insects it must be assumed that the smothering effect of depositing sediments would make egg hatching and development as precarious for insects as it has been found to be for fish (Chutter, 1968; Jones, 1966; Stroud, 1967; Hynes, 1974), thus restricting another method of recolonization. These facts lead one to the conclusion that streams receiving heavy sediment inputs will have low benthic insect faunal

densities and would recover only slightly, if at all, as long as heavy inputs continue. This conclusion is supported by Cumming and Donley (1971) who studied stream faunal recovery after manganese strip mine reclamation. Branson and Batch (1972) in discussing the effects of strip mining on small stream fish in Kentucky conclude that fish populations are eliminated primarily by lack of food due to the smothering of benthic invertebrates. They base this conclusion on observations that the first fish eliminated are bottom feeders while the surface feeding fish continue to persist with Semotilus atromaculatus being the most resistant.

CHAPTER IV

METHODS AND MATERIALS

A. SAMPLING PROCEDURE

It was desired to obtain as representative a sample as possible from each sampling sight. Artificial substrate samplers were considered but rejected because of the large number needed and the remoteness of many of the sampling sites. The Surber square-foot bottom sampler (Surber, 1936) is a commonly encountered sampling device that was considered, but it is not without its shortcomings. Needham and Usinger (1956) sampled a section of a riffle 100 feet long by 30 feet wide and found that 194 samples were required before they could say with 95% confidence that their samples were representative of the population present. Chutter (1972) objected to their statistics but agreed, in general, with their conclusions. Gaufin et al. (1956) found that, on the average. an eight sample composite contained between 85 and 90% of the total species present in a given habitat type. Allen (1959) said that the variation between samples of similar habitat is too great to be ascribed to random deviation and is probably due in part to the presence of undefined microhabitats. According to Hynes (1970), the important factor is to have some measure of the relative abundance of the species present and he cites the research of Harris (1957) as concluding that any method which involves the collection of several samples gives a fair indication of the abundance of the commoner species

in a given habitat. Morgan and Egglishaw (1965) proposed a simple method which gave consistent results and it is one of the methods used in this study. It consists of disturbing the substrate in a standardized way (in this case turning over and washing off rocks for a distance of one arm's length) upstream of a hand held screen. This method was used for a 30 minute time period at each site on each day samples were taken. To sample organisms not readily dislodged and consequently missed by this method, a second sampling method was employed. This involved picking the organisms from substrate particles with forceps. This method was also performed for 30 minutes at each site on each day samples were taken and the organisms collected were pooled with those collected using the screen. While ideally all samples should have been collected simultaneously to insure that the faunistic differences were not temporal ones, this was not possible. All samples were, however, collected with as little time lapse between sampling at the first and last sampling sites as humanly possible.

B. PRESERVATION AND IDENTIFICATION

Organisms were preserved in 70% alcohol and examined in the laboratory when the sampling period was over. The major references used in the identification of the organisms were: Plecoptera, Claassen (1931), Frison (1935, 1942), Hanson (1941, 1946, 1949, 1953), Ricker (1952), Baumann (1976), Needham and Claassen (1925); Diptera, Thomsen (1969); Trichoptera, Flint (1960, 1962, 1964), Ross (1944); Ephemeroptera, Needham, Traver, Hsu (1935), Traver (1937), Ide (1937), Berner (1950), Burks (1953), Lewis (1974); other orders, Usinger (1974).

A reference collection was assembled and used to assure consistency in identification. In addition to the quantitative samples, qualitative samples were taken where necessary to identify individuals as accurately as possible. Little success was had light trapping and so species whose accurate identification depends largely on the examination of adult specimens (i.e., Ephemeroptera) could not in most cases be identified beyond the level of species group. Trichoptera and Plecoptera were identified to species where possible by examining the adult genitalia of the metamorphosing pupae and preemergence nymphs, respectively. Coleoptera and Diptera were identified to genus level where possible.

C. PARAMETERS ANALYZED

Quantitative Parameters

Biotic communities can be analyzed in two general ways. One way is to measure biomass and production and define the community in terms of matter and energy. The second way, the approach taken in this investigation, is to analyze community structure and describe the community in terms of species frequency and the numerical abundance of species (Wilhm and Dorris, 1966; Hairston, 1959). Recent ecological studies are dominated by the use of species diversity indices to examine community structure. Dills and Rogers (1974), and Wilhm and Dorris (1968) discuss several species diversity indices and the advantages and disadvantages of each. Due to the fact that not all determinations in the present study were consistently made to species level, the index used was that proposed by Kuehne (1975),

$$D = N - 1/Lg_n I_t$$

where D is diversity, N is the total number of taxa, Lg_n is the natural logarithm, and I_t is the total number of individuals of all taxa in a sample. The diversity is at a maximum when each individual belongs to a different taxon and minimal when all individuals belong to the same taxon. Since species diversity indices have almost universally been used to assess the effects of organic pollution where the pattern is a reduction in species number with an increase in the number of individuals, there was some concern as to their value in a situation where all species are potentially reduced to the same extent.

An analysis of variance (Sokal and Rohlf, 1969) was done on the quantitative parameters to determine if there was a significant difference between the controls and post mining streams. To determine when recovery had progressed to such a degree that there was no longer a significant difference between the control group and an age group of experimental streams, Tukey's HSD test (Haber and Runyon, 1970) was performed.

Qualitative Parameters

Since a mere compilation of numbers of species or species diversity indices gives little more than an indication that the community structure is changing, it was decided to examine qualitatively the changes taking place. This was done by grouping the sampling sites according to the time interval since mining occurred to form a composite. Grouping was done to eliminate differences due to individual variations in the streams examined. The numbers of individuals of each order and the percent composition by order was then calculated and compared over time to examine recovery qualitatively.

D. SAMPLING SITE SELECTION

It was desired to sample locations which would be as similar faunistically as possible excluding the effects of mine drainage. To this end the factors affecting the occurrence of the benthic insect fauna needed to be identified and the streams being sampled needed to show as little variation as possible in these controlling factors.

Stream Characteristics

Hynes (1970) listed the most important factors controlling benthic invertebrates as current speed, the substratum, temperature, and dissolved material in solution. Harrel and Dorris (1968) found community structure to be related to stream order but found greater similarities between similar habitats in different order streams than between different habitats in streams of the same order. Kimble and Wesche (1975) concluded that the nature of the substrate appears to be the principal factor in determining faunal distribution. This conclusion is supported by Linduska (1942) who found that mayfly distribution is determined by substrate, and by Pennak and Van Gerpen (1947) who described the benthic faunas associated with different substrates. Percival and Whitehead (1929) recognized seven types of substrate and found that certain species were consistently associated with each. Hunt (1930) and Ellis (1936) in studies in the southern Appalachian region also recognized the importance of substrate type in determining the benthic fauna. Barber and Kevern (1973) in a study of the ecological factors influencing macroinvertebrate distribution found ephemeropteran and trichopteran numbers and biomass to be related to substrate type with

trichopterans showing greater numbers and biomass with increasing substrate particle size.

The streams in the study are similar in all the factors Hynes (1970) mentioned except current speed, substratum, and dissolved materials. The differences in dissolved materials are due in large part to strip mining and it was not desired that the streams be similar in this respect. Current speed and substrate differed at various points in the study streams. Since current speed to some extent determines the substrate type (Kimble and Wesche, 1975) and since substrate type is commonly considered to be the most important factor controlling the benthic community, it was felt that if samples were taken in areas of similar substrate they would be faunistically similar excluding the effects of strip mining in the watersheds. For these reasons sampling was confined to riffle areas where the substrate particles were at least four to six inches in size.

Watershed Characteristics

Watershed characteristics affecting water quality in the study streams were considered to be soil type, degree of slope, and amount of disturbance to the watershed (Greene, 1975). Soil type was considered constant and the degree of slope in the mined watersheds is relatively constant (Larson, 1975), so no effort was made to group the watersheds on this basis. The extent of disturbance to the watersheds differed widely, however, and had to be considered to assure comparability. Most watersheds in which more than one coal seam had been mined were excluded from the investigation. Exceptions were made in the cases of Jake

Branch, Bletchers Creek, and Sugarcamp Creek where, although two seams were mined, the total disturbance was comparable to that in the other watersheds.

E. SEASON OF SAMPLING

Numerous investigators have found that there is a striking difference in the faunal composition of the same stream where sampling is done at different times of the year (Tebo and Hassler, 1961; Nelson and Scott, 1962; Armitage, 1958; Hynes, 1970). In addition to a change in composition by orders, there is also a change in biomass and numbers of individuals at various seasons. The general pattern is a decline in numbers of spring and early summer as insects emerge, an increase in late summer and autumn as eggs hatch, and a decline over winter with mortality but no recruitment. Tebo and Hassler (1961) give the composition by order during different months of the year for two streams in North Carolina. They found ephemeropterans to peak in April, decline over summer, and reach a secondary peak in September before plummeting to a minimum from December to February. Trichopterans in general reached a high level in June which was maintained all summer and peaked in September with a minimum being recorded from January to April. Dipterans exhibited two peaks, one in September and one in March. Plecopterans reached a maximum in July and remained at a high level from May to November. It is clear from these investigations that any survey conducted over a short time span in only one season of the year is unlikely to describe totally the community present on a yearly basis. This fact was recognized but circumstances were such that samples for this

investigation were only taken during June and July; peak times for trichopterans and plecopterans, but a time of seasonal decline in ephemeropteran population levels. Since all samples were taken at this time, however, it is felt that they are comparable and are of value in assessing the effects of surface mining on a major component of the benthic fauna of the streams studied.

F. RESULTS

The locations of the sampling stations are given in Table 4. A list of the species collected and the station where each was collected is given in the Appendix.

Quantitative Analysis

The quantitative parameters analyzed—number of individuals, number of taxa, and species diversity index—are presented in Table 5. The results of an analysis of variance on the three parameters are given in Table 6. As is evident from Figure 5, the species diversity index continues to decrease after the cessation of mining, reaching a minimum in four to six years. With the exception of the inexplicably high values for the streams in the 10 years since mining range, recovery appears to be gradual, with predisturbance diversity values being attained in the 21 and 22 years since mining streams (Table 7).

Analysis of the total number of individuals collected in each stream (Figure 6), shows that they exhibit the same recovery pattern of sharp decline and gradual increase as is shown by the species diversity index. Again, recovery appears to be complete in the 21 and 22 years since mining streams (Table 7).

TABLE 4

SAMPLING STATION LOCATIONS AND COLLECTION DATES

Station No.	Name	Drainage	Location	County	Date Collected
1	Indian Fork	Trib. to New River	.7 mi. NE of Moores Camp on TN 116	Anderson	June 1, 1976
2	Ursery Branch	Trib. to New River	.2 mi. E of Shiloh Church TN 116	Anderson	June 1, 1976
3	Bills Branch	Trib. to Smokey Creek	1.2 mi. S of Hembree, 6.4 mi. SW of Co. Rd. 2344	Scott	June 1, 1976
4	Shack Creek	Trib. to Smokey Creek	.2 mi. SW of Hembree, 6.4 mi. SW of Co. Rd. 2344	Scott	June 1, 1976
5	Bowling Branch	Trib. to Smokey Creek	2.2 mi. SW of Smokey Junction on Co. Rd. 2344	Scott	June 1, 1976
6	Anderson Creek	Trib. to New River	1.3 mi. SSW of Montgomery Junction, W of Co. Rd. 2344	Scott	June 1, 1976
7	Lowe Branch	Trib. to New River	.9 mi. SSW of Montgomery Junction, W of Co. Rd. 2344	Scott	June 1, 1976
8	Jake Branch	Trib. to Straight Fork	at TN Hwy 63 on Scott-Campbell County Line	Scott Campbell	June 2, 1976
9	1st Unnamed Trib.	Trib. to Brimstone Creek	1.8 mi. NE of Mt. Pleasant Church off Co. Rd. 2342	Scott	June 2, 1976

TABLE 4 (Cont'd)

Station No.	Name	Drainage	Location	County	Date Collected
10	2nd Unnamed Trib.	Trib. to Brimstone Creek	.8 mi. NE of Mt. Pleasant Church off Co. Rd. 2342	Scott	June 2, 1976
11	Number One Hollow	Trib. to Brimstone Creek	1.3 mi. NE of Mt. Pleasant Church off Co. Rd. 2342	Scott	June 2, 1976
12	Cowan Creek	Trib. to Wolf Creek	2.8 air miles E. of Mill Creek	Scott	June 2, 1976
13	Dry Branch	Trib. to Emory River	3.1 air miles ENE of U.S. 27 Bridge	Morgan	June 3, 1976
14	Hall Branch	Trib. to Emory River	6.4 air miles ENE of U.S. 27 Bridge	Morgan	June 3, 1976
15	Bletchers Creek	Trib. to Crooked Fork	2 mi. E of Petros off TN 116	Morgan	June 3, 1976
16	Sugarcamp Creek	Trib. to New River	1.3 mi. E of Morgan Co. Line, off TN 116	Anderson	June 4, 1976
17	1st Unnamed Trib.	Trib. to New River	.8 mi. E of Morgan Co. Line, off TN 116	Anderson	June 4, 1976
18	Duncan Creek	Trib. to Cove Creek	.2 mi. N of Caryville on Cove Creek Rd.	Campbell	June 5, 1976
19	Yellow Branch	Trib. to Ollis Creek	2.8 air miles E of Huntsville Exit of I-75	Campbell	June 5, 1976
20	Louse Creek	Trib. to Hickory Creek	.7 mi. SW of Health Clinic on Stinking Creek Rd	Campbell	June 5, 1976

TABLE 4 (Cont'd)

Station No.	Name	Drainage	Location	County	Date Collected
21	Hickory Creek	Trib. to Stinking Creek	.5 mi. SW of Health Clinic on Stinking Creek Rd.	Campbell	June 5, 1976
22	Kent Hollow	Trib. to Big Creek	.3 mi. W of U.S. 25 at Ivydell	Campbell	June 6, 1976
23	Jenny Creek	Trib. to Montgomery Creek	3 mi. E of Montgomery Junction off Co. Rd. 2344	Scott	June 6, 1976
24	Indian Fork	Trib. to New River	.7 mi. NE of Moores Camp on TN 116	Anderson	July 1, 1976
25	Ursery Branch	Trib. to New River	.2 mi. E of Shiloh Church off TN 116	Anderson	July 1, 1976
26	Bills Branch	Trib. to Smokey Creek	1.2 mi. S of Hembree, 6.4 mi. SW of Co. Rd. 2344	Scott	July 1, 1976
27	Shack Creek	Trib. to Smokey Creek	.2 mi. SW of Hembree, 6.4 mi. SW of Co. Rd. 2344	Scott	July 1, 1976
28	Bowling Branch	Trib. to Smokey Creek	2.2 mi. SW of Smokey Junction on Co. Rd. 2344	Scott	July 1, 1976
29	Anderson Creek	Trib. to New River	1.3 mi. SSW of Montgomery Junction, W of Co. Rd. 2344	Scott	July 1, 1976
30	Lowe Branch	Trib. to New River	.9 mi. SSW of Montgomery Junction, W. of Co. Rd. 2344	Scott	July 1, 1976

TABLE 4 (Cont'd)

Station No.	Name	Drainage	Location	County	Date Collected
31	Jake Branch	Trib. to Straight Fork	at TN Hwy 63 on Scott-Campbell County Line	Scott Campbell	July 2, 1976
32	1st Unnamed Trib.	Trib. to Brimstone Creek	1.8 mi. NE of Mt. Pleasant Church off Co. Rd. 2342	Scott	July 2, 1976
33	2nd Unnamed Trib.	Trib. to Brimstone Creek	.8 mi. NE of Mt. Pleasant Church off Co. Rd. 2342	Scott	July 2, 1976
34	Number One Hollow	Trib. to Brimstone Creek	1.3 mi. NE of Mt. Pleasant Church off Co. Rd. 2342	Scott	July 2, 1976
35	Cowan Creek	Trib. to Wolf Creek	2.8 air miles E Mill Creek	Scott	July 2, 1976
36	Dry Branch	Trib. to Emory River	3.1 air miles ENE of U.S. 27 Bridge	Morgan	July 3, 1976
37	Hall Branch	Trib. to Emory River	6.4 air miles ENE of U.S. 27 Bridge	Morgan	July 3, 1976
38	Bletchers Creek	Trib. to Crooked Fork	2 mi. E of Petros off TN 116	Morgan	July 3, 1976
39	Sugarcamp Creek	Trib. to New River	1.3 mi. E of Morgan Co. Line, off TN 116	Anderson	July 4, 1976
40	1st Unnamed Trib.	Trib. to New River	.8 mi. E of Morgan Co. Line, off TN 116	Anderson	July 4, 1976
41	Duncan Creek	Trib. to Cove Creek	.2 mi. N of Caryville on Cove Creek Rd.	Campbell	July 5, 1976

TABLE 4 (Cont'd)

Station No.	Name	Drainage	Location	Scott	Date Collected
42	Yellow Branch	Trib. to Ollis Creek	2.8 air miles E of Huntsville Exit of I-75	Campbell	July 5, 1976
43	Louse Creek	Trib. to Hickory Creek	.7 mi. SW of Health Clinic on Stinking Creek Rd.	Campbell	July 5, 1976
44	Hickory Creek	Trib. to Stinking Creek	.5 mi. SW of Health Clinic on Stinking Creek Rd.	Campbell	July 5, 1976
45	Kent Hollow	Trib. to Big Creek	.3 mi. W of U.S. 25 at Ivydell	Campbell	July 6, 1976
46	Jenny Creek	Trib. to Montgomery Creek	3 mi. E of Montgomery Junction off Co. Rd. 2344	Scott	July 6, 1976

TABLE 5

YEARS SINCE AFFECTED, NUMBER OF ORGANISMS, NUMBER OF TAXA,
AND SPECIES DIVERSITY INDICES FOR STREAMS SAMPLED

Name	Years Since Affected	Number of Organisms			Number of Taxa			Species Diversity Index		
		June	July	Total	June	July	Total	June	July	Total
Anderson Cr.	Control	160	115	275	19	20	31	3.54	4.00	5.34
Lowe Br.	Control	313	83	396	21	22	29	3.48	4.75	4.68
Bowling Br.	Control	207	211	418	15	27	27	2.62	2.92	4.31
Bills Br.	A	61	112	173	13	16	20	2.91	3.17	3.68
Hickory Cr.	3	11	8	19	7	2	9	2.50	0.48	2.71
Indian Fork	4	9	30	39	7	4	8	2.73	0.88	1.91
Yellow Br.	4	15	21	36	4	5	6	1.10	1.31	1.39
Jenney Cr.	6	0	0	0	0	0	0	-	-	-
Louse Cr.	6	18	17	35	6	7	7	1.72	1.76	1.68
Ursery Br.	6	55	119	174	14	10	16	3.24	1.88	2.96
Shack Cr.	7	38	63	101	11	10	15	2.74	2.17	3.03
Kent Hollow	8	9	4	13	5	4	8	1.82	2.16	2.72
Jake Br.	10	82	150	232	17	14	23	3.63	2.59	4.03
Number One Hollow	10	194	56	250	22	18	27	3.98	4.22	4.75
Trib. 1 to Brimstone Cr.	10	130	52	182	16	19	23	3.08	4.55	4.22
Trib. 2 to Brimstone Cr.	10	202	171	373	18	16	25	3.20	2.91	4.05
Cowan Cr.	14	189	208	397	22	20	26	4.00	3.55	4.16
Bletchers Cr.	15	165	43	208	13	12	19	2.15	2.92	3.37
Sugarcamp Cr.	15	54	59	113	12	17	20	2.75	3.92	4.03
Trib. 1 to New River	15	100	-	100	14	-	14	2.82	-	2.82
Duncan Cr.	21	107	118	225	20	21	29	4.06	4.19	5.16
Dry Br.	22	219	158	377	24	18	26	4.26	3.35	4.21
Hall Br.	22	190	141	331	26	27	31	4.76	5.25	5.17

TABLE 6

ANALYSIS OF VARIANCE SUMMARIES FOR THE QUANTITATIVE PARAMETERS EXAMINED

Source	D.F.	S.S.	M.S.	F
Species Diversity Index				
Between groups	5	20.5	4.1	10.96[1]
Within groups	17	6.3	0.37	
Total	22	26.8		
Number of Individuals				
Between groups	5	1,227,296	245,459	43.91[1]
Within groups	17	95,018	5,589	
Total	22	1,322,314		
Number of Taxa				
Between groups	5	1,271	254.2	21.54[1]
Within groups	17	201	11.8	
Total	22	1,472		

[1]Significant at the .001 level.

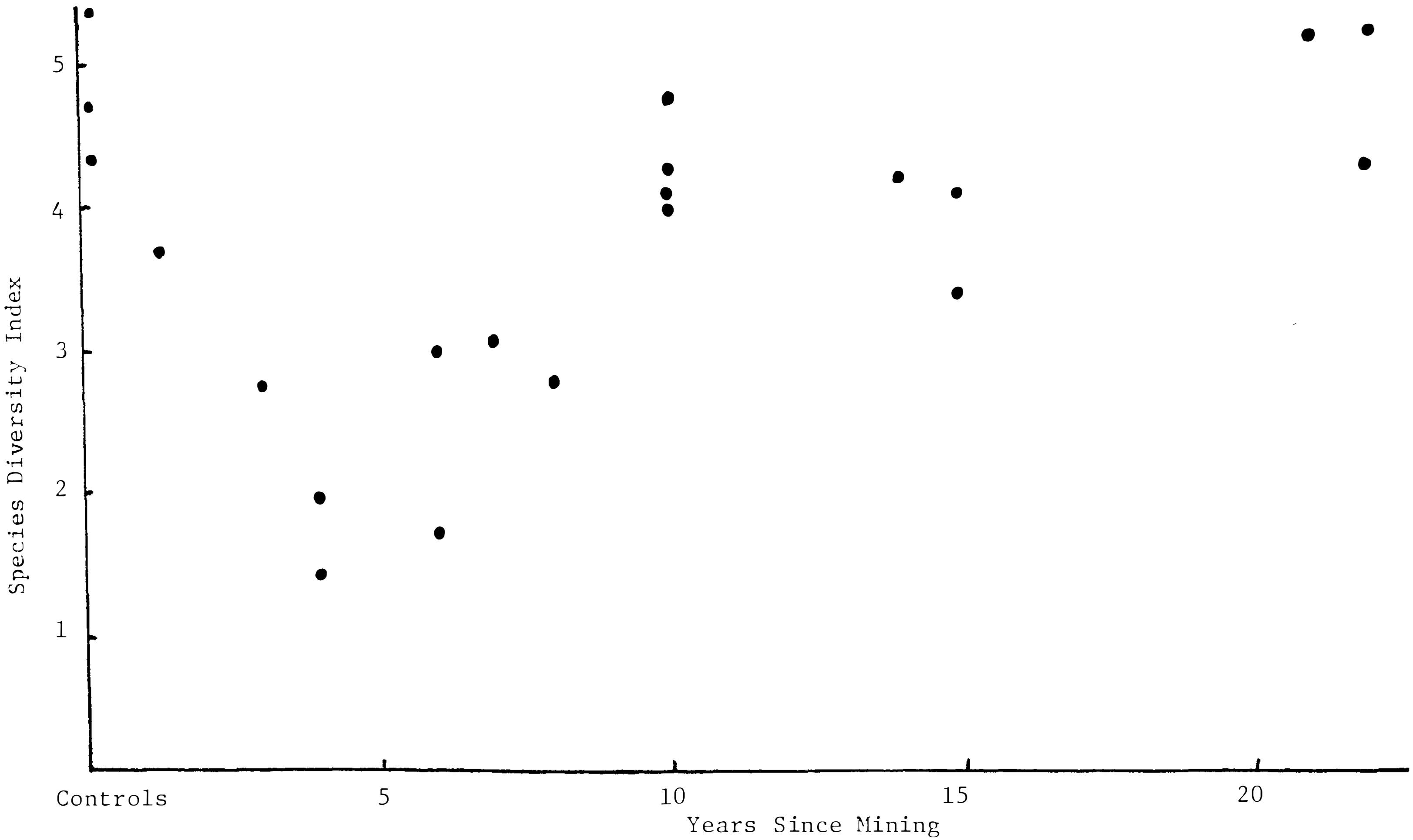

Figure 5. Species diversity index vs time since mining.

TABLE 7

SUMMARY OF RESULTS OF TUKEY'S HSD TEST BETWEEN MEANS OF STREAM AGE GROUPS

Source	$\bar{X}$ 10-14 Years	$\bar{X}$ 15-20 Years	$\bar{X}$ Over 20 Years
Species Diversity Index			
$\bar{X}$ Control	.63[2]	1.37[1]	-.07[2]
$\bar{X}$ 15-20 Years	-.74[2]	-	-1.44[2]
$\bar{X}$ Over 20 Years	.70[2]	-	-
Number of Individuals			
$\bar{X}$ Control	76[2]	188[1]	50[2]
$\bar{X}$ 15-20 Years	-112[2]	-	138[2]
$\bar{X}$ Over 20 Years	26[2]	-	-
Number of Taxa			
$\bar{X}$ Control	5.06[2]	10.16[1]	.99[2]
$\bar{X}$ 15-20 Years	-5.10[2]	-	9.16[1]
$\bar{X}$ Over 20 Years	4.06[2]	-	-

[1]Reject H_0 at .05 level (H_o; $\bar{X}$ row = $\bar{X}$ column).

[2]No reason to reject H_o at .05 level.

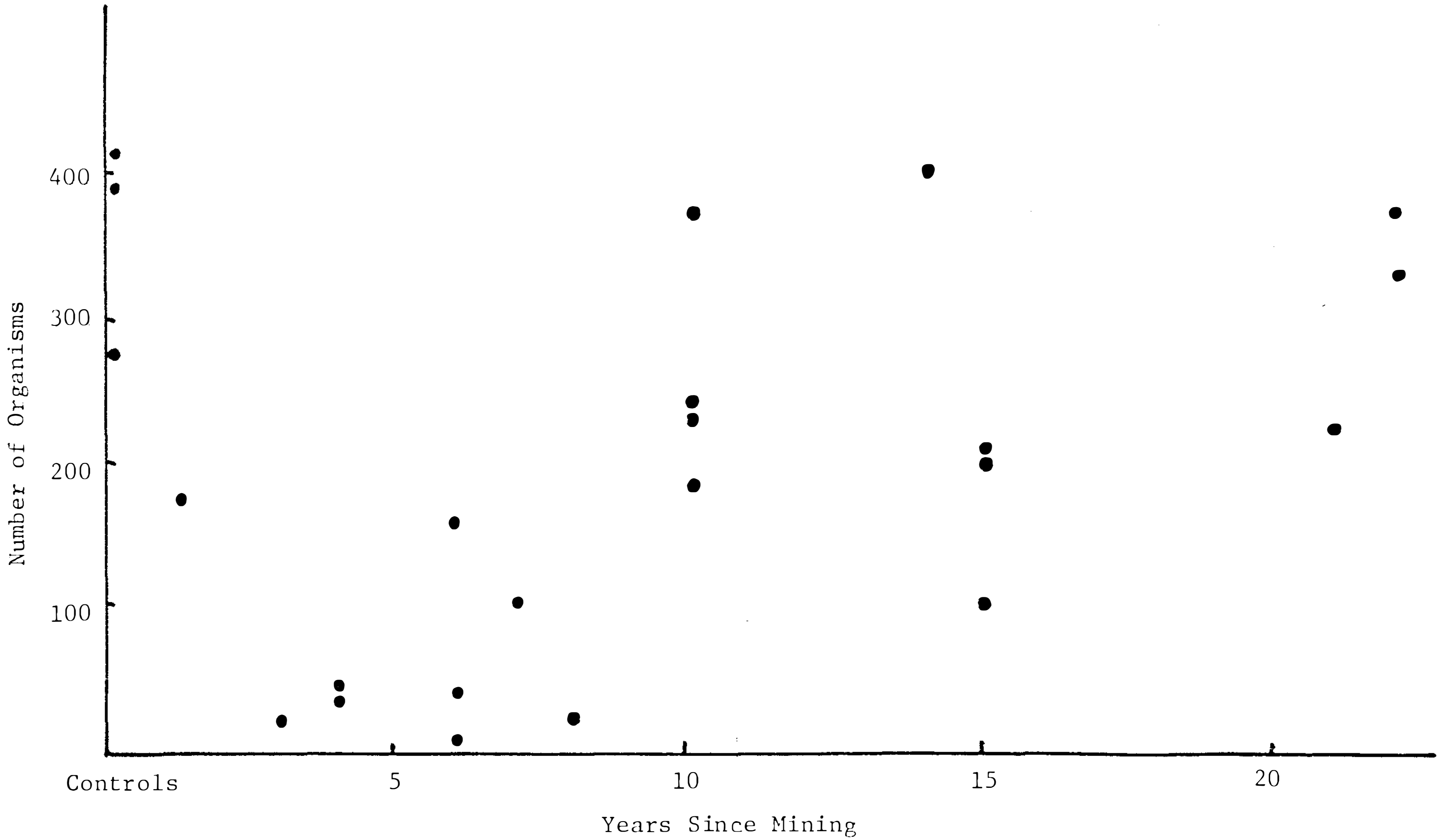

Figure 6. Total number of organisms collected vs time since mining.

The total number of taxa collected for each stream (Figure 7 and Table 7) shows the same recovery pattern as the plots of species diversity index and number of individuals. In this study the total number of taxa collected in a stream appears to be as sensitive an indicator of stream condition as the species diversity index, probably because no species increased in number as the total number of taxa decreased as is often the case in studies dealing with the effects of organic pollution.

Qualitative Analysis

General community recovery trends. Data resulting from the qualitative analysis of the study streams are given in Tables 8 and 9. In order to minimize the effects of individual stream faunal variations the streams were grouped into composite streams based on the time elapsed since mining. The composites were: The controls, active to 4 years, 5 to 9 years, 10 to 14 years, 15 to 20 years, and over 20 years. The number of individuals by order in each composite stream was determined by summing the number found in each stream of that age group and dividing by the number of streams.

(a) Changes in number of individuals by order. The number or individuals by order is given in Figures 8 and 9. The most obvious changes are in the Ephemeroptera and Trichoptera. All orders decreased initially. Ephemeroptera showed the most precipitous decline and very little recovery over time. The Trichoptera declined initially but recovered to such an extent that population levels were reached that were higher than those in predisturbance streams. Absolute numbers of Plecoptera, Diptera, and Coleoptera showed an initial decline with essentially complete recovery over the time span covered by the study.

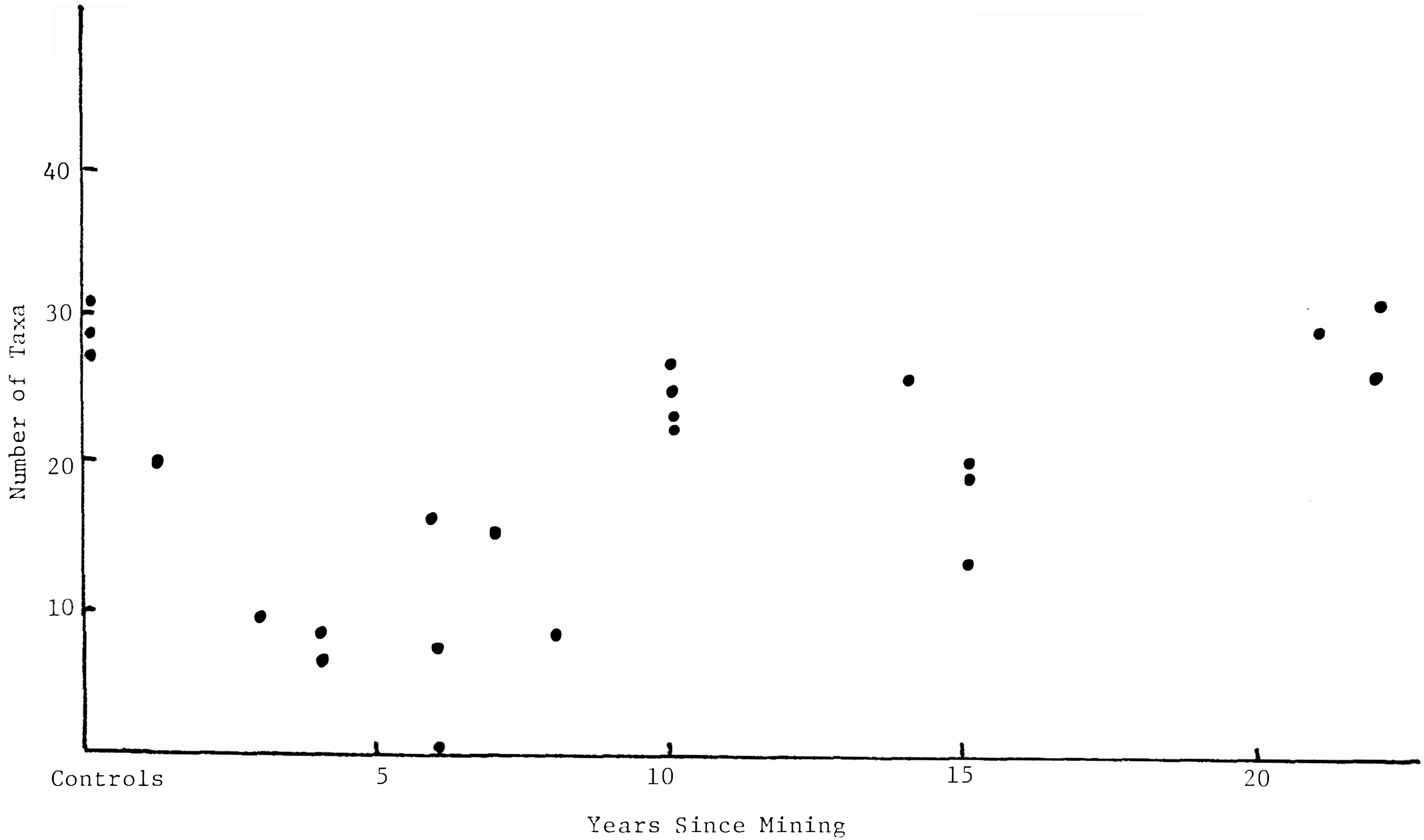

Figure 7. Total number of taxa collected vs time since mining.

TABLE 8

QUALITATIVE DESCRIPTION OF COMMUNITY STRUCTURE FOR THE ORDERS TRICHOPTERA, EPHEMEROPTERA, AND PLECOPTERA

Years Since Affected	Name	No. of Organisms	Trichoptera No.	Trichoptera &	Ephemeroptera No.	Ephemeroptera %	Plecoptera No.	Plecoptera %
	Anderson Cr.	275	48	17.45	174	63.27	27	9.82
Control	Bowling Br.	413	30	7.26	315	76.27	35	8.47
	Lowe Br.	396	47	11.26	286	72.22	23	5.80
	Composite	1084	125	11.53	775	71.49	85	7.84
A	Bills Br.	173	37	21.38	90	52.02	29	16.76
3	Hickory Cr.	19	1	5.55	0	0	8	38.88
4	Indian Fork	39	23	58.97	9	23.07	6	15.38
4	Yellow Br.	36	12	33.33	0	0	0	0
Active-4	Composite	267	73	27.34	99	37.07	43	16.10
8	Kent Hollow	13	3	23.07	3	23.07	1	7.69
6	Louse Cr.	35	3	8.57	0	0	11	31.42
7	Shack Cr.	101	31	30.69	46	45.54	7	6.93
6	Ursery Br.	157	36	22.92	108	68.78	13	8.28
5-9	Composite	306	73	23.85	157	51.30	32	10.45
14	Cowan Cr.	407	60	14.74	277	68.05	25	6.14
10	2nd trib. to Brimstone	374	233	62.29	93	24.86	34	9.09
10	Jake Br.	232	73	31.46	142	61.20	9	3.87
10	1st trib. to Brimstone	182	12	6.59	116	63.73	18	9.89
10	Number One Hollow	237	26	10.97	113	47.67	36	15.18
10-14	Composite	1432	404	28.21	741	51.74	122	8.51
15	Bletchers Cr.	208	42	20.19	149	71.63	5	2.40
15	1st trib. to New River	101	5	4.95	81	80.19	12	11.88
15	Sugarcamp Cr.	111	33	29.72	45	40.54	13	11.71
15-30	Composite	420	80	19.04	175	41.66	30	7.14
22	Dry Br.	377	138	36.60	158	41.90	16	4.24
21	Duncan Cr.	336	84	37.16	77	34.07	49	21.68
22	Hall Br.	331	73	22.05	163	49.24	33	9.96
21-25	Composite	934	295	31.58	398	42.61	98	10.49

TABLE 9

QUALITATIVE DESCRIPTION OF COMMUNITY STRUCTURE FOR THE ORDERS ODONATA, COLEOPTERA, DIPTERA, AND MEGALOPTERA

Years Since Affected	Name	No. of Organisms	Odonata		Coleoptera		Diptera		Megaloptera	
			No.	%	No.	%	No.	%	No.	%
	Anderson Cr.	275	0	0	2	.73	16	5.82	8	2.9
Control	Bowling Br.	413	1	.24	0	0	20	4.84	4	.96
	Lowe Br.	396	0	0	8	2.02	32	8.08	0	0
	Composite	1084	1	.092	10	.92	68	6.27	12	1.10
A	Bills Br.	173	0	0	0	0	17	9.82	0	0
3	Hickory Cr.	19	0	0	4	22.22	6	33.33	0	0
4	Indian Fork	39	0	0	0	0	1	2.56	0	0
4	Yellow Br.	36	0	0	0	0	4	11.11	20	55.55
Active-4	Composite	267	0	0	4	1.49	28	10.48	20	7.49
8	Kent Hollow	13	0	0	1	7.69	0	15.38	3	23.07
6	Louse Cr.	35	0	0	3	8.57	7	20.00	11	31.42
7	Shack Cr.	101	0	0	8	7.92	6	5.94	3	2.97
6	Ursery Br.	157	0	0	0	0	16	10.19	1	.63
5-9	Composite	306	0	0	12	3.92	31	10.13	18	5.88
14	Cowan Cr.	407	0	0	8	1.96	35	8.59	2	.49
10	2nd trib. to Brimstone	374	0	0	1	.26	13	3.47	0	0
10	Jake Br.	232	1	.43	3	1.29	1	.43	3	1.29
10	1st trib. to Brimstone	182	0	0	8	4.39	24	13.18	4	2.19
10	Number One Hollow	237	0	0	32	13.50	30	12.65	1	.42
10-14	Composite	1432	1	.06	52	3.63	103	7.19	10	.69

TABLE 9 (Cont'd)

Years Since Affected	Name	No. of Organisms	Odonata No.	Odonata %	Coleoptera No.	Coleoptera %	Diptera No.	Diptera %	Megaloptera No.	Megaloptera %
15	Bletchers Cr.	208	1	.48	6	2.88	5	2.40	0	0
15	1st trib. to New River	101	0	0	1	.99	2	1.98	0	0
15	Sugarcamp Cr.	111	0	0	0	0	20	18.01	0	0
15-20	Composite	420	1	.23	7	1.66	27	6.42	0	0
22	Dry Br.	377	0	0	40	10.61	19	5.03	6	1.59
21	Duncan Cr.	336	0	0	4	1.76	6	2.65	6	2.65
22	Hall Br.	331	1	.30	34	10.27	17	5.13	10	3.02
>20	Composite	934	1	.10	78	8.35	42	4.49	22	2.35

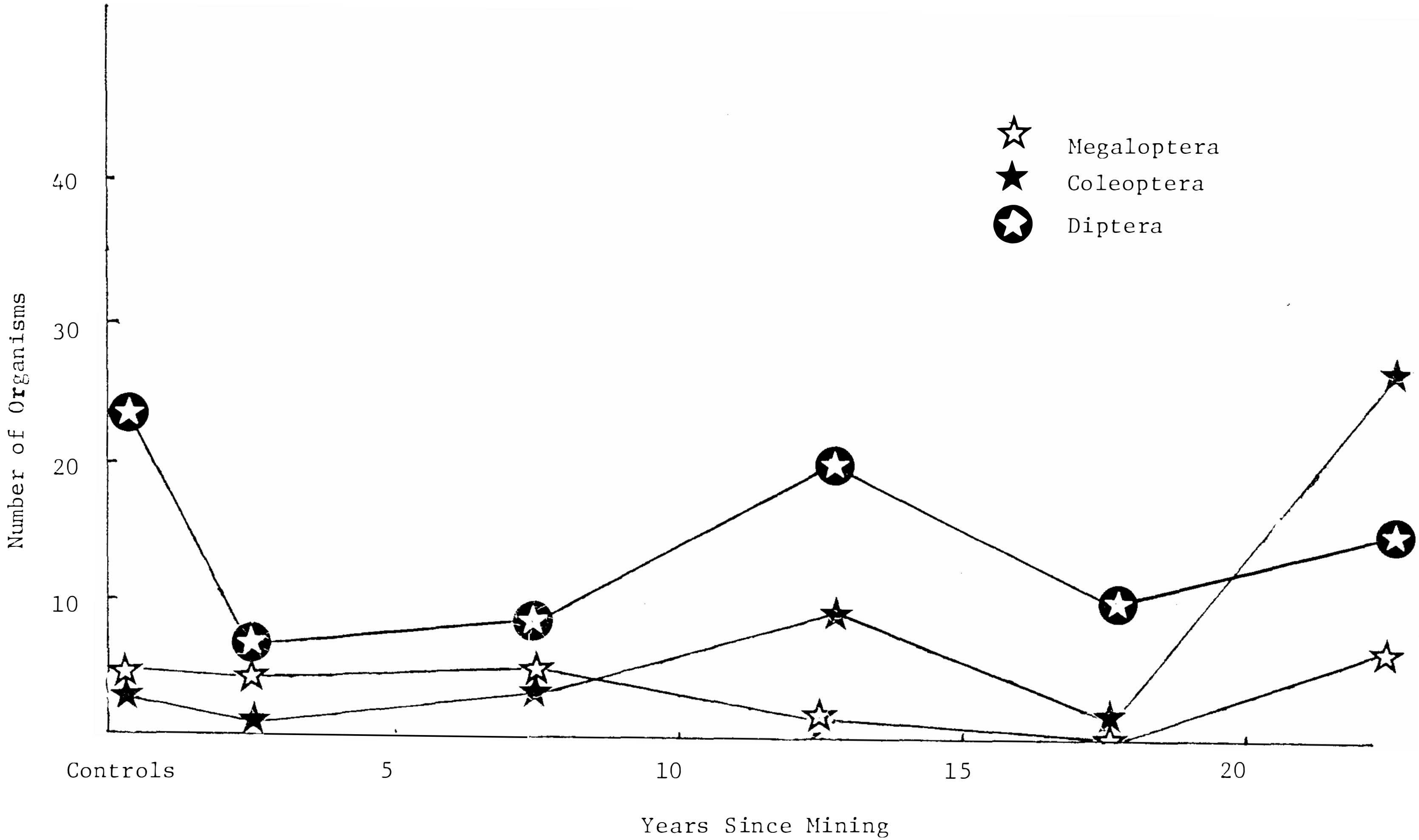

Figure 8. Number of organisms by order in composite streams vs time since mining; Coleoptera, Diptera, Megaloptera.

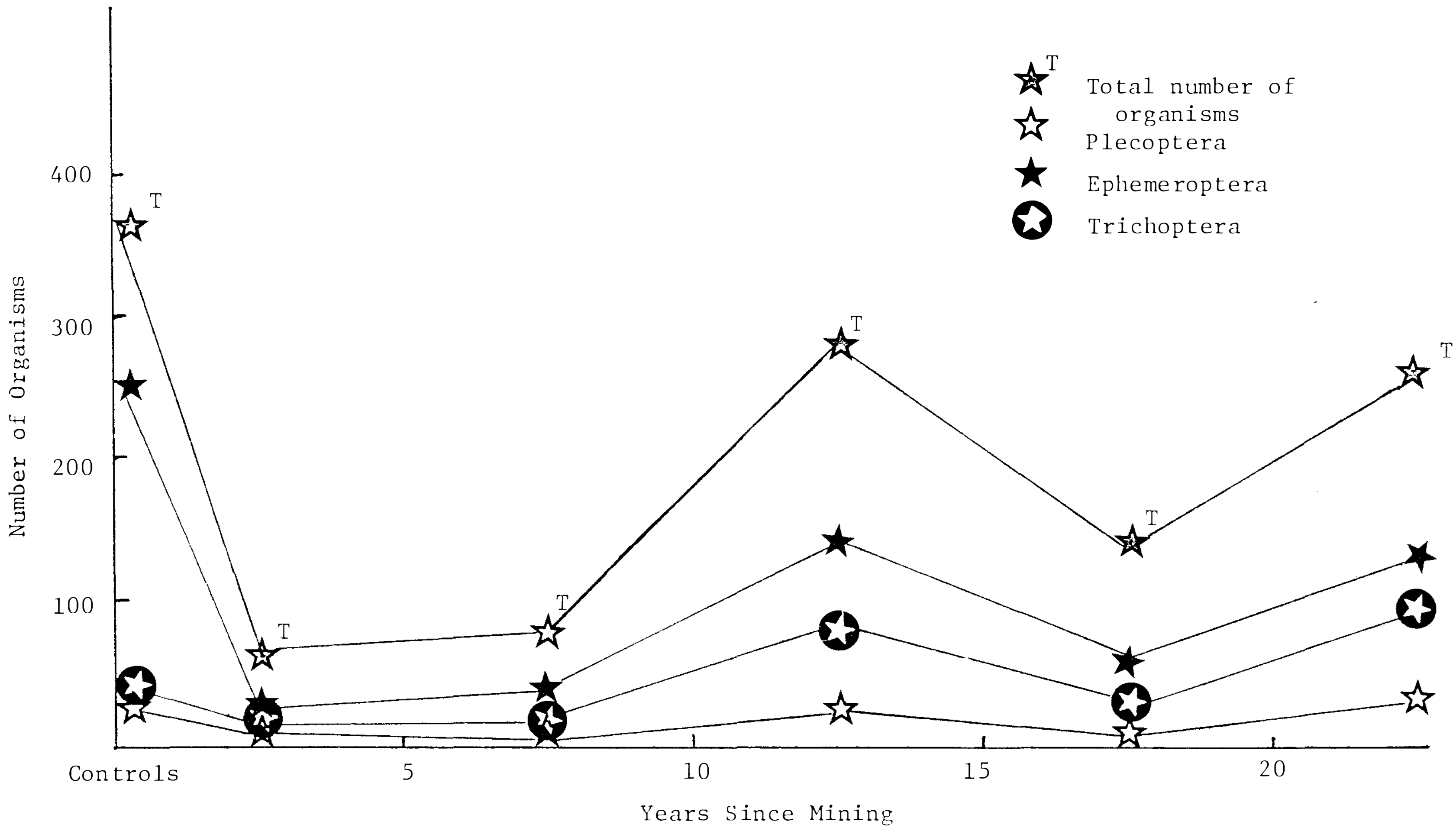

Figure 9. Number of organisms by order in composite streams vs time since mining; Ephemeroptera, Plecoptera, Trichoptera.

(b) Changes in percent composition by order. The percent composition by order in the composite streams is shown in Figures 10 and 11. The percent of the total community belonging to the orders Diptera, Megaloptera, and Plecoptera first increased and then returned to predisturbance levels indicating that these orders are not affected as much by mining activities as the other orders. The percentage of the total made up by Ephemeroptera declined from 70% to less than 40% and recovered only slightly during the time span covered by the study. This indicates that the Ephemeroptera are the most seriously affected by mining activities. The Trichoptera (predominantly Hydropsychidae) increased from 11% of the total community in the control streams to 32% of the total in the 22 years since mining streams. This indicates that the Trichoptera were relatively better suited to conditions in the distrubed streams. The increase in Coleoptera in the "over 20 year" category is the result of inexplicably high populations of Psephenus sp. in two of the streams and is probably not consistent with the overall recovery pattern.

Detailed recovery pattern. In order to better assess the relative importance to stream faunal recovery of the various alterations in the aquatic environment occurring as a result of strip mining, recovery was analyzed at the species level where possible. This analysis was only performed on New River tributaries, under the assumption that there was no reason to expect the species present to differ on similar substrates in tributaries of the same area in a river. Undoubtedly factors exist which would cause individual variation in the

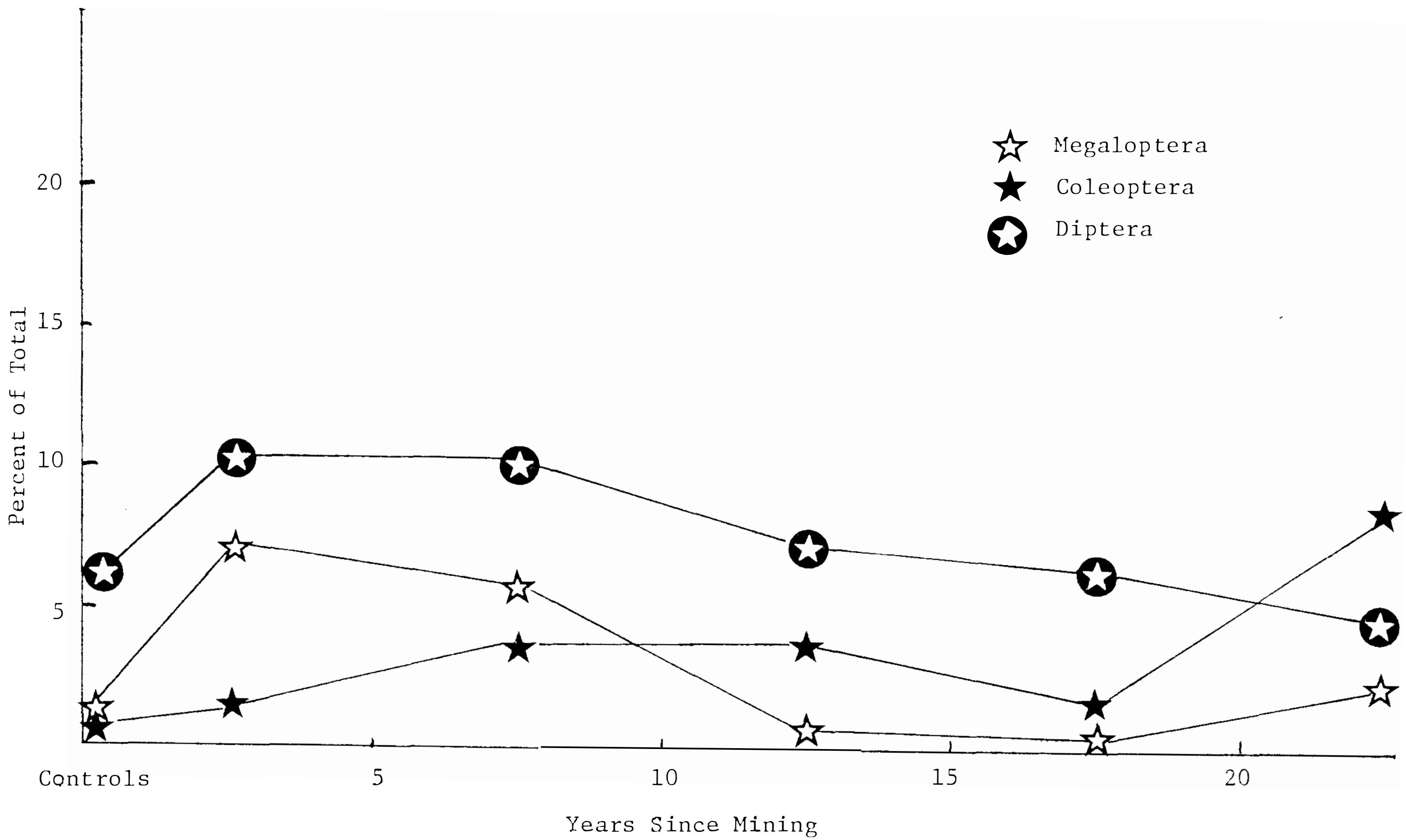

Figure 10. Percent composition by order in composite streams vs time since mining; Coleoptera, Diptera, Megaloptera.

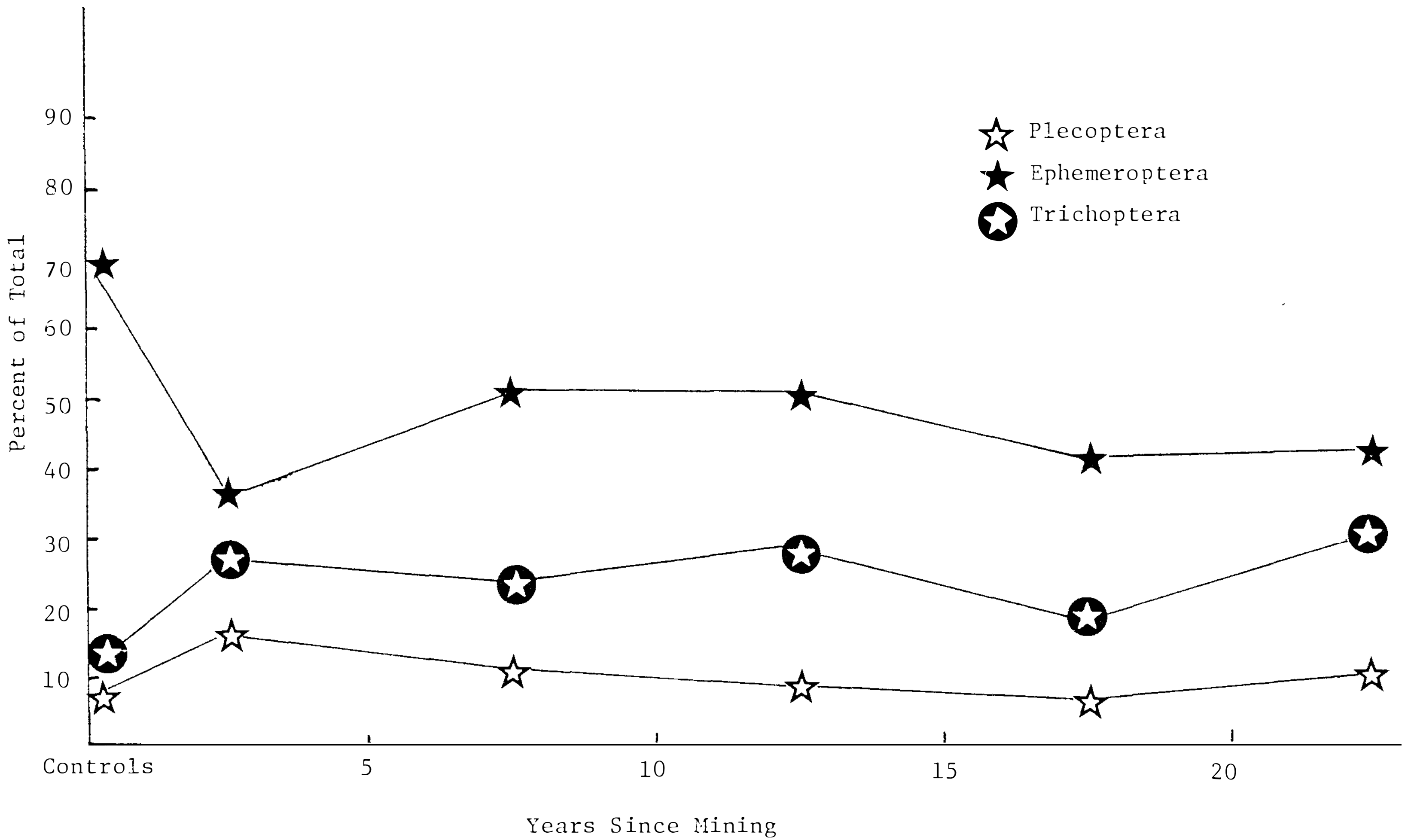

Figure 11. Percent composition by order in composite streams vs time since mining; Ephemeroptera, Plecoptera, Trichoptera.

streams as no pooling of streams of the same "age" was possible. The effect of the mining variable is assumed to be predominant however.

(a) Plecoptera. Figure 12 shows the response of Plecoptera. Population levels of Isoperla clio, Nemoura nigritta, Peltoperla sp., and Chloroperla terna were relatively unaffected by water quality changes resulting from mining activities. Members of the species Isogenus decisus and Alloperla mediana occurred only rarely and no assessment could be made of the effects of mining on populations of these two species. Acroneuria sp., Phasganophora capitata, Leuctra sibleyi, and L. carolinensis were all totally eliminated by mining and were not collected in any streams where mining had occurred in the previous ten years.

(b) Ephemeroptera. The most dramatic declines in population levels occurred in the Heptageniidae (Figure 13). Members of the genera Heptagenia and Stenonema were eliminated by mining and only began to reappear at greatly reduced population levels after seven years. Stenonema pulchellum, S. interpunctatum, and the maculipennis group of the genus Heptagenia were eliminated and did not reappear within the time span covered by the study. Members of the genus Epeorus presisted after the cessation of mining, being found in one stream four years after mining, but they too were eventually eliminated and began to reappear 10 years after mining.

Within the Baetidae (Figure 14) only two genera were seriously effected. Paraleptophlebia were eliminated and reappeared after six years. Ephemerella (both the walkeri and invaria groups) were eliminated and only began to reappear after 10 years at greatly reduced population levels.

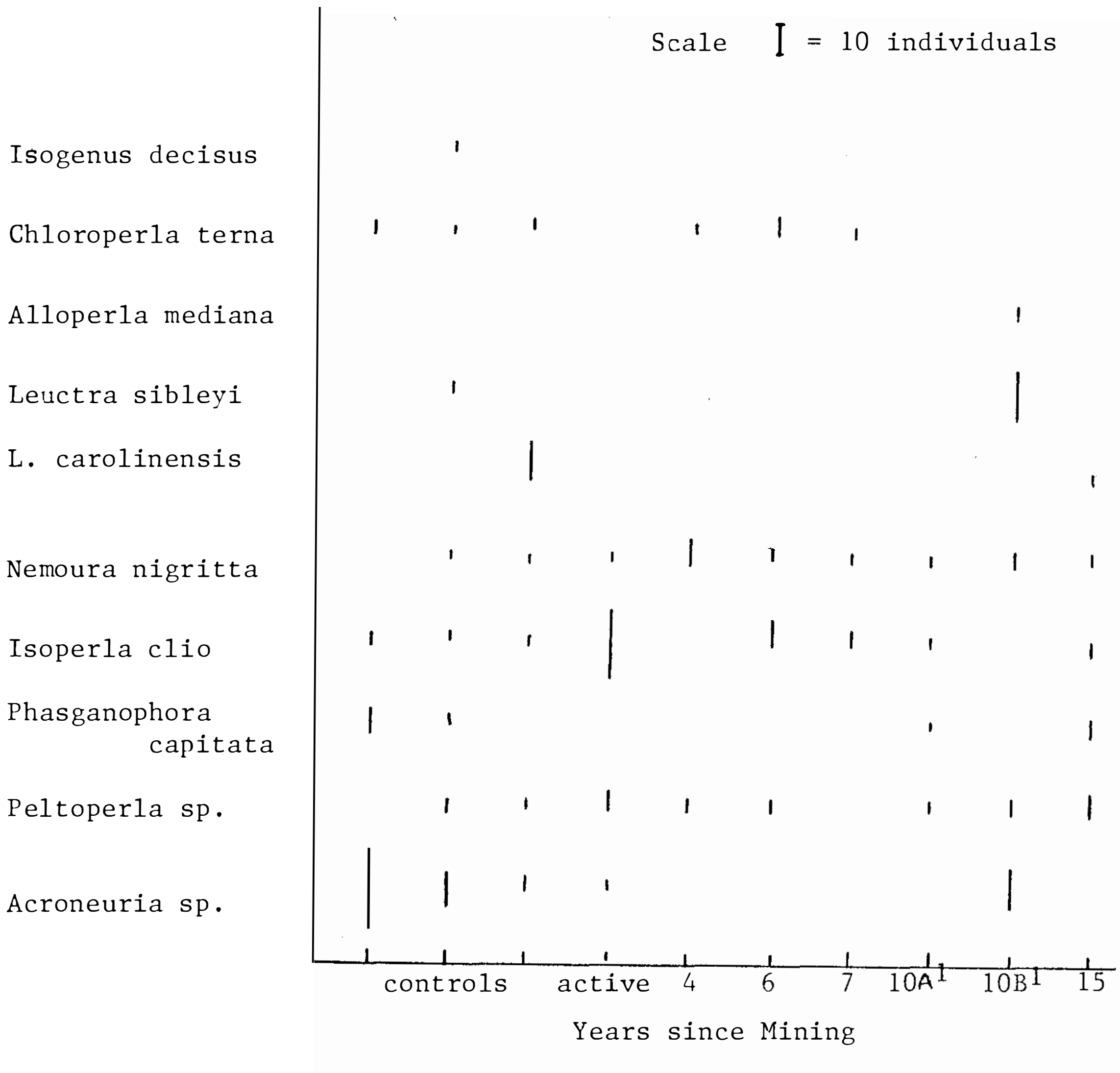

Figure 12. Number of Plecoptera vs time since mining for New River tributaries.

[1] 10A has slightly greater watershed disturbance than 10B.

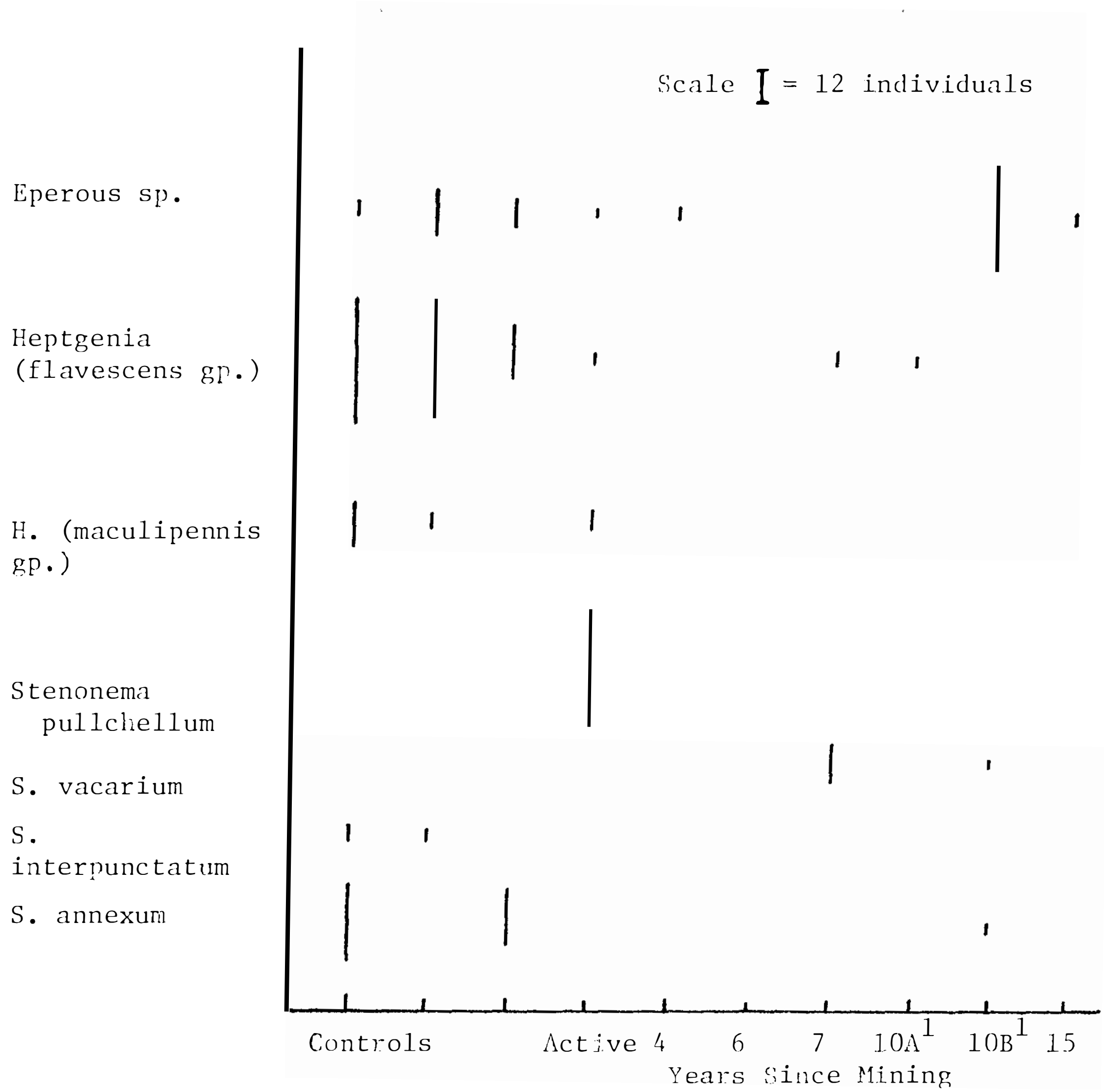

Figure 13. Number of Heptageniidae vs time since mining for New River tributaries.

[1] 10A has slightly greater watershed disturbance than 10B.

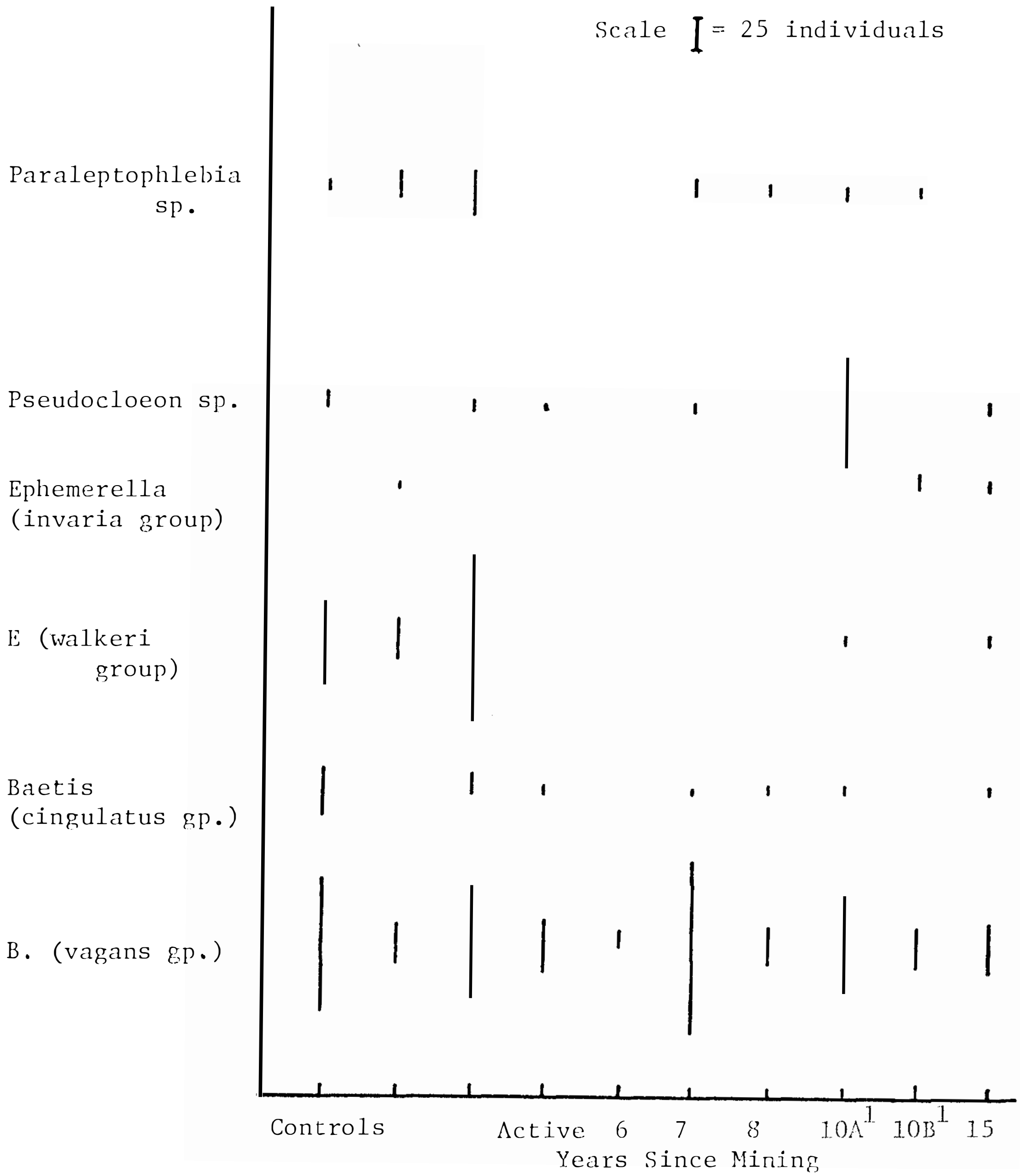

Figure 14. Number of Baetidae vs time since mining for New River tributaries.

[1] 10A has slightly greater watershed disturbance than 10B.

(c) Trichoptera. As is shown in Figure 15, the genera Hydropsyche, Cheumatopsyche, and Diplectrona were not seriously affected by water quality changes resulting from mining activities. Glossosoma nigrior and Rhyacophila nigritta were eliminated but reappeared after 10 years. Neophylax sp. was eliminated but reappeared in the "10 years since mining" streams. Curiously enough an unidentified species of Polycentropus occurred in post-mining streams but not in any of the control streams.

(d) Diptera. As is evident from Figure 16 the only discernible effect of mining activities on dipteran populations in this study is an elimination of the genera Eriocera and Tipula with both reappearing after six years.

(e) Coleoptera. As shown in Figure 16, both the genus Psephenus and the family Elmidae were eliminated but reappeared seven years after mining.

(f) Megaloptera. Representatives of this order were only collected rarely and it is not possible to assess recovery at a taxonomic level below order.

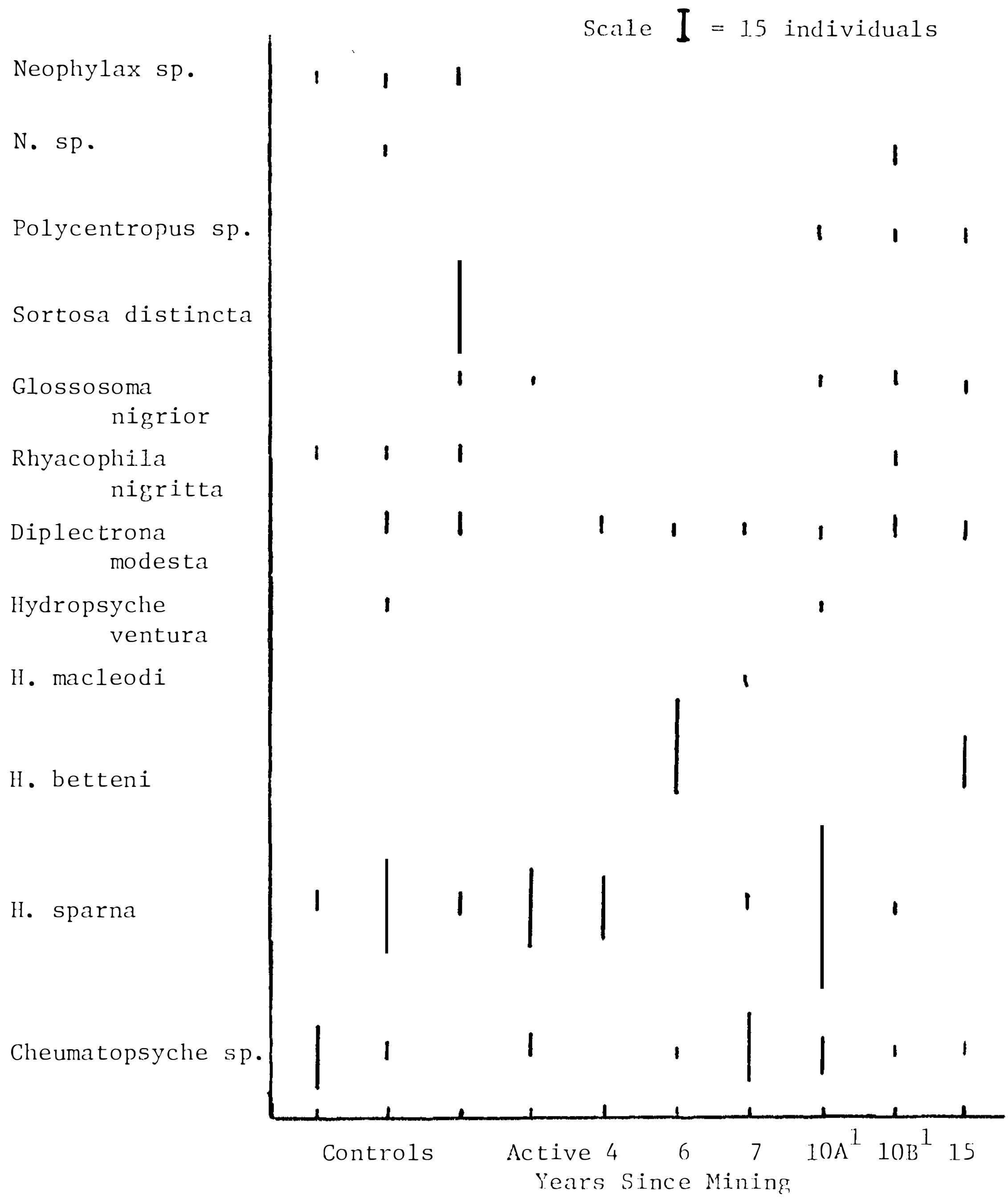

Figure 15. Number of Trichoptera vs time since mining for New River tributaries.

[1] 10A has slightly greater watershed disturbance than 10B.

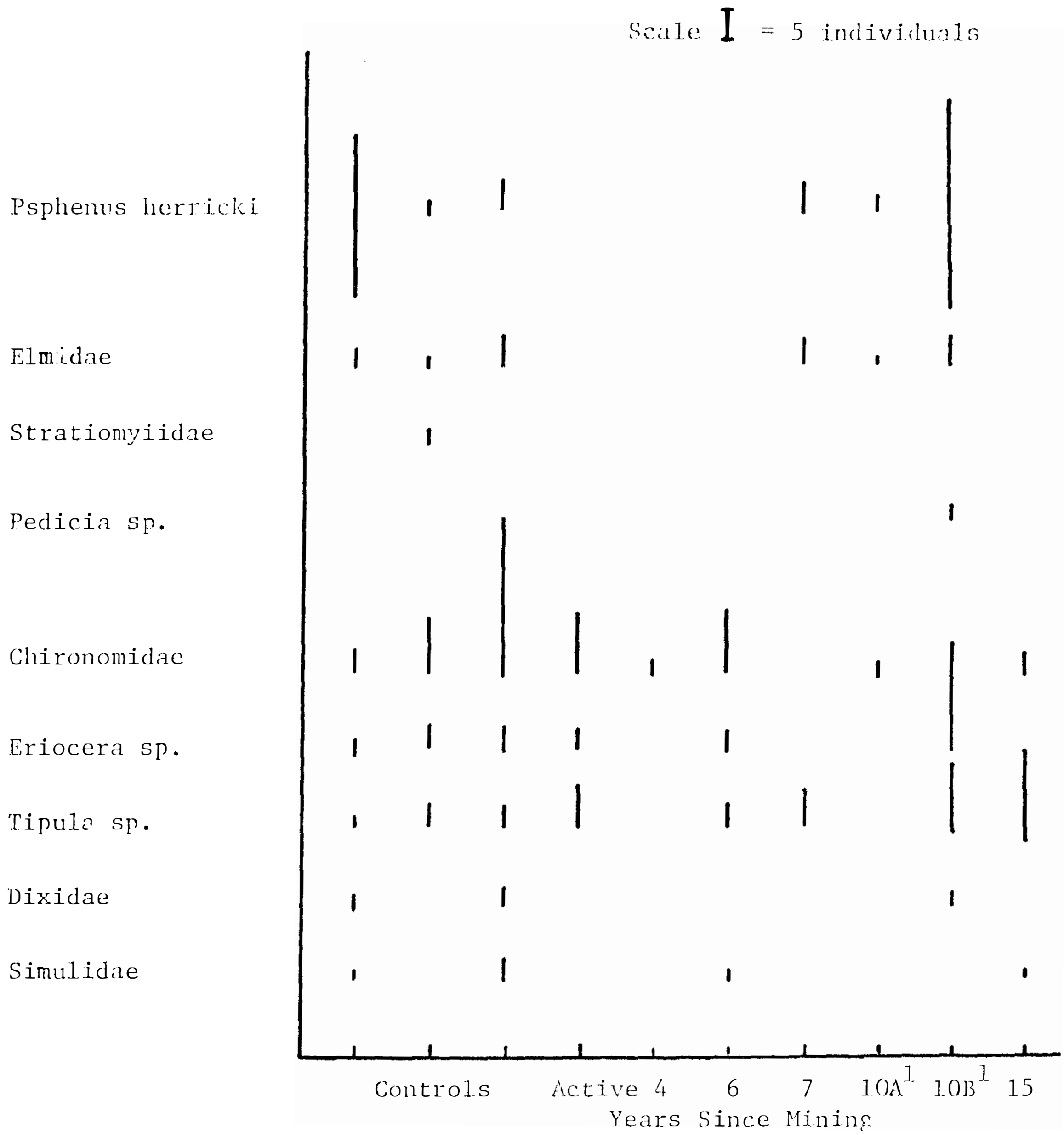

Figure 16. Number of Diptera and Coleoptera vs time since mining for New River tributaries.

[1]10A has slightly greater watershed disturbance than 10B.

CHAPTER V

DISCUSSION

Analysis of biological communities reveals much about the physical and chemical characteristics of an environment. In water pollution studies the benthic community easily sampled quantitatively and is an index of long term water quality, whereas chemical and physical tests are instantaneous and may or may not reflect the usual conditions of a water. In the present study, however, both the physical-chemical data and analysis of the benthic insect community support the same conclusion, that siltation is the major pollution problem resulting from contour coal surface mining.

The two major effects of coal surface mining on aquatic ecosystems are acid mine drainage and increased siltation. Acid mine drainage was not considered a major problem in the present study due to low sulfur concentrations in the coal and overburden of the Cumberland Mountains and the greater proportion of alkaline materials in the Pennsylvanian strata of Tennessee (Elmore, 1961; Anon., 1968;, Anon., 1969a). Both Curtis (1972) and Larson et al. (1975) found that both the ph and alkalinity of streams in the southern Appalachian region actually often increase after surface mining. This behavior is explained by the fact that in undisturbed watersheds runoff acquires only a very small mineral load and hence has a low alkalinity. pH in these undisturbed streams is controlled by dissolved atmospheric carbon dioxide and is relatively low (Larson, 1975). After mining, the

alkalinity increases due to increased leaching from the disturbed surface areas of the watershed. This results in a greater acid neutralizing capacity and a higher ph (Upham, 1975).

Analysis of the biological communities of the study streams supports the conclusion that acid drainage is not a serious problem in the study area. It was found in the present study that both the number of taxa and the number of individuals decreased after mining with no taxa showing a significant increase in numbers. This pattern differs from that reported for streams receiving acid drainage by Parsons (1956) and Dills and Rogers (1974). These investigators found a decrease in number of taxa but an increase in number of individuals of certain taxa, similar to the response pattern of waters receiving organic pollution (Bartsch, 1959; Keup, 1966). Neither of these studies agrees with such laboratory studies on the effects of ph on aquatic insects as those of Bell and Nebeker (1969) and Butler et al. (1973). Current thought is that ph is not as important in determining community structure as the actual ionic composition of the water which is a function of area geology (Dills and Rogers, 1974; Warnick and Bell, 1969).

Physical-chemical studies of streams receiving drainage from contour strip mining all show a tremendous increase in suspended solids (Plass, 1967; Branson and Batch, 1972; Curtis, 1972, 1973; Larson et al. 1976). In a study in the New River area of the Cumberland Mountains of Tennessee (Larson et al., 1976), it was found that suspended solids regularly exceeded 1,000 mg/l and occasionally exceeded 10,000 mg/l in streams draining mined watersheds. This is in contrast

to undisturbed streams where suspended solids consistently remained below 25 mg/1.

The community response pattern to increased inputs of silt is the same as the response observed in the study streams, i.e., a reduction in number of taxa and number of individuals with no significant increase in the number of individuals in any taxon (Cumming and Donley, 1971).

The recovery curves for the quantitative perameters analyzed in this study (species diversity index, number of taxa, and number of individuals) all show a similar pattern. All three values continue to decrease after the cessation of mining, reaching a minimum after approximately four years before recovering gradually to predisturbance levels. This response coincides closely with changes in sedimentation observed by Curtis (1972) who found that suspended solids loads increased with mining, reaching a maximum after one year, and returning essentially to predisturbance levels three years after the cessation of mining.

Qualitative analysis of community composition supports the conclusion that sedimentation is the most serious effect of contour coal surface mining on stream ecosystems. Ephemeropterans in predisturbance streams accounted for 70% (by number) of the community. They were reduced to less than 40% of the total in post-mining streams and did not recover during the course of the study. The most serious reduction occurred in the herbiverous (Leonard, 1965) Heptageniidae. The periphyton grazers Glossosoma nigrior and Psephenus sp. were also totally eliminated and slow to reappear, as were the herbiverous

plecopterans Leuctra sibleyi and L. carolinensis. Filter feeders such as Diplectrona modesta, Cheumatopsyche sp. and Hydropsyche sp. (Roback, 1965) as well as such detritus feeders as Peltoperla sp., Nemoura nigritta, and Baetis sp. were relatively unaffected by mine runoff. Such predators as Isoperla clio (Gaufin, 1965) and the various megalopterans were also relatively unaffected. These facts would lead one to the conclusion that the most seriously effected component of the community is the component dependent on autochthanous primary production. All these data are consistent with the premise that siltation, whether through substrate smothering or a reduction in light penetration, is the major adverse change brought about in stream systems as a result of contour coal mining.

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APPENDIX

TABLE A.1

SPECIES LIST AND COLLECTION LOCALITIES

Organism	Station Where Collected
Ephemeroptera	
Beatidae	
Ameletus sp.	10,12
Baetis (cingulatus group)	2,4,5,7,8,9,12,14,15,16,23,26,28,31, 38,39
B. (vagans group)	1,3,4,5,6,7,8,9,10,12,13,15,16,18,23, 24,25,26,27,28,29,30,31,32,34,35,36, 37,39,41
Empherella (invaria group)	6,10,12,16,35,41
E. (walkeri group)	5,6,8,12,13,14,28,29,35,36,37,38,41
Isonychia sp.	5,26
Paraleptophelbia sp.	2,5,6,7,8,9,10,12,13,14,18,28,30,32, 34,35,36,37,38
Pseudocloeon sp.	2,3,5,8,14,15,26,28,30,31,39,41
Heptageniidae	
Epeorus sp.	1,3,6,7,9,10,12,13,14,15,16,18,23, 28,32,35,41
Heptagenia (flavescens group)	3,4,5,6,7,8,12,13,14,18,26,27,28,29 30,31,35,36,37.41

TABLE A.1 (Cont'd)

Organism	Station Where Collected
H. (maculipennis group)	5,13,18,26,29,30,32,36,37
Stenonema annexum Traver	5,7,13,14,28,30,34,36,37,41
S. interpunctatum (Say)	5,13,28,29,34,37
S. pulchellum (Walsh)	3,26
S. vicarium (Walker)	4,15,27,34,38
Plecoptera	
Perlidae	
Acroneuria abnormis (Newman)	5,6,7,11,14,18,26,28,29,30,35,37,41
A. carolinensis (Banks)	6,7,10,11,14,16,23,32,35,44
A. ruralis (Hagen)	10,18,29,38
Phasganophora capitata (Pictet)	5,8,18,20,28,29,31,37,39,43
Peltoperlidae	
Peltoperla sp.	1,2,3,4,8,10,12,16,23,24,26,29,30, 31,34,35,36,39,41,45
Leuctridae	
Leuctra (Leuctra) sibleyi Claassen	6,11,13,34
L. (Leuctra) carolinensis Claassen	7,9,39
Perlodidae	
Isogenus (Cultus) decisus Walker	6,12,35

TABLE A.1 (Cont'd)

Organism	Station Where Collected
I. sp.	15
Isoperla clio Newman	2,3,5,9,13,18,23,26,27,29,30,31,36,39
Chloroperlidae	
Alloperla mediana Banks	10,11
Chloroperla terna Frison	1,2,4,5,9,12,13,14,18,25,29,30,35
Nemouridae	
Nemoura (Amphinemura) nigritta Provancher	1,2,3,4,6,7,8,10,11,12,16,21,35,37
Trichoptera	
Rhyacophilidae	
Glossosoma nigrior Banks	8,11,12,13,15,18,23,26,30,34,35,36,37, 39,41
Rhyacophila fuscula Walker	14,18,41
R. nigritta Banks	6,35,41
R. parantra Ross	17
Philopotamidae	
Sortosa distincta (Walker)	7,9,12,13,14,18,23,30,32,35,36,37
Psychomyiidae	
Polycentropus cinereus Hagen	18,41
P. confusus Hagen	8,31
P. sp.	12,13,14,37,39
Hydropsychidae	
Cheumatopsyche sp.	4,5,8,15,27,31,38

TABLE A.1 (Cont'd)

Organism	Station Where Collected
Diplectrona modesta Banks	1,2,8,9,10,11,13,14,16,18,19,23,24, 25,27,28,29,30,32,34,37,39,41
Hydropsyche betteni Ross	2,10,15,16,39,41
H. macleodi Flint	27
H. sparna Ross	4,5,12,14,18,24,25,26,29,30,31,32,34, 36,37,38,45
H. ventura Ross	29,31
Limnephilidae	
Neophylax sp.	6,7,10,11,13,14,15,18,23,29,34,35,36, 37,41
Pycnopsyche gentilis (McLachlan)	12,22,32
Lepidostomatidae	
Lepidostoma sp.	14,32
Megaloptera	
Corydalidae	
Corydalus cornutus Linnaeus	4
Nigronia fasciata Walker	6,8,12,13,18,19,22,29,32,36,37,42,45
N. serricornis (Say)	5,8,14,20,28,37,43
Sialidae	
Sialis sp.	19,25,31,32,34,42

TABLE A.1 (Cont'd)

Organism	Station Where Collected
Coleoptera	
Helichus sp.	5,11,14,18,20,21,22,27,29,31,34,35,36, 37,38,43
Psephenus herricki	5,6,7,11,12,13,14,15,18,27,28,30,32, 34,35,36,37,41
Stenelmis sp.	7,12,30
Odonata	
Boyeria vinosa McLachlan	5,31,37,38
Diptera	
Tipulidae	
Tipula sp.	2,3,4,5,6,7,9,10,11,13,14,19,20,21, 23,25,26,27,29,30,34,35,37,38,39,41, 42,43,44,45
Pedicia sp.	11,15,43
Eriocera sp.	2,3,5,6,7,9,11,12,13,14,23,26,29,30, 32,34,35,36,37
Chironomidae	1,2,3,5,6,7,8,9,10,11,12,15,16,18,30, 21,25,26,29,30,32,34,35,36,37,41,42
Stratiomyiidae	
Nemotelus sp.	6
Simuliidae	5,7,9,14,25,30,32,39
Dixidae	5,7,30,34,37

VITA

Anthony Talak, Jr. was born on January 8, 1948 in Pittsburgh, Pennsylvania where he attended elementary and high school. He graduated in June, 1965 from St. Canice High School. He attended Duquesne University under a PHEAA scholarship until he entered the Army in 1967. He served as an interpreter with the Americal Division in Viet Nam and was discharged in 1971.

He attended California State College in California, Pennsylvania from which he graduated with highest honors in January, 1974 with a B.A. in Environmental Studies. After graduation, he was employed by the Monongahela Valley Council of Governments as the Director of the Rodent Control Program.

He entered the University of Tennessee Graduate Program in Ecology in September, 1974 and graduated with an M.S. in Ecology in March, 1977. He is currently employed with the surface mining section of the Water Quality Control Division of the State of Tennessee.

He is married to the former Suzanne Florence Musial of Pittsburgh, Pennsylvania, a 1970 graduate of Penn State University.