THE STATUS AND SEASONAL DYNAMICS OF FISH AND BENTHIC INVERTEBRATE POPULATIONS IN RELATION TO ORGANIC AND INORGANIC MATERIAL INPUTS AND SURFACE MINING IMPACTS IN THREE VIRGINIA HEADWATER STREAMS

by

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INTRODUCTION

In the assessment of environmental impacts on natural systems, it is appropriate to first examine the functioning of natural systems and then to seek out differences in perturbed systems.

The Stream Ecosystem

Streams, as unidirectional flowing water bodies, are unique ecosystems. They are characterized as "open" systems (Odum 1971), with little opportunity for nutrient or mineral recycling (Krunholz and Neff 1970; Webster 1975), and therefore require continual resupply of life support materials from upstream areas. Small woodland streams receive a majority of their energy inputs from the adjacent terrestrial system in the form of vegetative litter (Nelson and Scott 1962; Cummins et al. 1973; Boling et al. 1975). Hynes (1975) has described how the surrounding watershed, in fact, governs nearly every character of its stream.

System "recharging" occurs, in part, through the processing of terrestrially-derived organic and inorganic matter or "allochthonous" material into available nutrients and foodstuffs for lotic organisms. Organic litter may enter a stream as small particles described as "fine-particulate organic matter" (FPOM) or as large particles termed "large-particulate organic matter" (LPOM).

FPOM is the product of biologic and physical action, primarily on LPOM. Terrestrial LPOM is reduced on land to FPOM by microbial attack and the processes of weathering, with transport into streams by wind and water action (Attiwill 1968; Fisher and Likens 1973; McDowell and

Fisher (1976). Once within the stream, LPOM is reduced to FPOM by molar and other abrasive actions of the stream flow, by structural weakening resulting from colonization by bacteria and fungi, and through ingestion, gut passage, and egestion by invertebrate shredders and collectors (Mathews and Kowalczewski 1969; Kaushik and Hynes 1971; Cummins 1974; Boling et al. 1975). FPOM undergoes additional reduction in particle size with greater microbial colonization and may be reduced or increased in size following ingestion by invertebrate collectors, especially where coprophagy is a factor (Cummins 1973; Cummins et al. 1973). Fragmented aquatic macrophytes and whole and fragmented microphytes, primarily diatoms, can make a limited contribution to FPOM (Nelson and Scott 1962; Minshall 1967; Egglishaw and Shakley 1971; Karlstrom and Backlund 1977). Even dissolved organic material (DOM) in the water column adds to the total FPOM through abiotic particle formation or flocculation (Cummins et al. 1972; Lush and Hynes 1973) and through bacterial assimilation leading to growth and reproduction of cell bodies. The complex formed by FPOM and its attached microbial community is called organic detritus.

LPOM, primarily leaf and twig litter, represents a large part of allochthonous particulate inputs to streams (Minshall 1967; Fisher and Likens 1973; McDowell and Fisher 1976) and is a major source of dissolved organic matter as well as FPOM (Attiwill 1968; Cummins et al. 1972; Lock and Hynes 1976). After rapid leaching of readily soluble materials, the rate of leaf decay depends on leaf composition, degree of preconditioning in the soil, the quality and temperature of the water, the type of microflora, and the degree of biotic and abiotic disruption (Nelson and Scott 1962; Kaushik and Hynes 1968, 1971; Mathews and Kowalczewski 1969; Cummins 1974). Fungi which elaborate extracellular enzymes (e.g. cellulase and pectinase) dominate the microbial flora of LPOM during the initial phases of processing, followed by increases in bacterial microflora in later stages (Triska 1970; Suberkropp and Klug 1976).

Benthic invertebrates are dependent on the energy inputs provided by organic detritus. Benthic "shredders" and "collectors", through ingestion, digestion, and excretion, contribute to the reduction of detrital particle size and increase the area available for microbial colonization. Moreover, the quantity and quality of microbial colonization on detrital particles directly influences their palatibility for detritivores (Kaushik and Hynes 1968; Triska 1970; Cummins et al. 1973), thereby directly regulating the degree of mechanical breakdown via animal feeding. Microbial colonization not only hastens further particle breakdown, but also adds to the benthic food base in that the bulk of the nutritional benefits accrued to detrital feeders is the product of the microbial coating rather than the particle substrate itself (Egglishaw 1964; Cummins et al. 1973).

Although some fish may be able to benefit from the direct ingestion of detrital material (Hynes 1970), most species meet their energy requirements by consuming benthic invertebrates or those fish which do. Hynes (1970) has suggested that fish influence biotic communities more by their feeding habits than by any other means. Almost all stream life is bound to the detrital food chain, directly or indirectly.

In addition to their unidirectional nature, streams are dynamic systems. Natural stream water quality is a product of watershed geology and hydrology coupled with meteorological phenomena. Although allochthonous organic material enters streams continually, it exhibits a regular pattern of peak abundance, generally in the fall and spring (Nelson and Scott 1962; Fisher and Likens 1973; Webster 1975). Hynes (1970) presented an excellent discussion and review of benthic invertebrate life histories and patterns of seasonal dynamics in flowing water. Since light, temperature, and other physical parameters largely control development and emergence, benthic life cycles may display marked geographic specificity, especially in headwater streams. Temporal changes in the composition and abundance of fish within a given stream reach may be due to growth, natality, and mortality or the result of movements into or out of the section associated with spawning, feeding, water level fluctuations, or random "wandering" (Funk 1957).

In light of the charge by Hynes (1975) that we must come to an appreciation of streams, "as parts of the valleys that they drain," it is clear that flowing water habitat evaluation, rehabilitation, and management should be based on sound knowledge of the energetics and dynamics of the stream ecosystem. Cummins (1974) suggested that the basic problem in stream management is the maintenance of "water quality," where the term is used in the broad sense to mean system integrity. Water quality status as affected by natural or human-based perturbations may be monitored by identifying appropriate relationships between the organic material pool and key functional groups of organisms. Hynes (1970) hypothesized that the differences in production rates between acid and alkaline streams may result from variation in the microoganism-benthic invertebrate community interchange. Cummins (1974) stated that "polluted" running water systems and relatively undisturbed woodland streams differ in organic particle characteristics, size distribution, and time of input as well as in temperature and nutrient regimes and functional groups of organisms. Webster (1975) documented that a larger percentage of vegetative inputs was carried out of disturbed stream systems as large particulate detritus when compared to a natural hardwood forest stream, suggesting greater retention and detrital processing efficiency in the more "mature" forest stream. Differences in the abundance of important functional groups of organisms were also linked to detrital processing efficiency in the study.

The Effects of Contour Surface Mining

A major watershed disturbance which can have profound impacts on streams is contour surface mining for coal, commonly referred to as strip mining. In an effort to reduce foreign petroleum imports, the U.S. has committed itself to increased coal production. Nearly 70 percent of any such increase would probably be met by surface mining operations (Minear and Tschantz 1976). (Physical, chemical, and biological changes in streams as a result of surface mining in the watershed could alter the relations between functional groups of organisms, resulting in changes in the efficiency and rate of detrital processing.)

(Preliminary study (Maughan et al. 1977; Matter et al. 1978) has shown that only small headwater streams of the southwestern coal mining districts of Virginia are free from multiple impacts associated with surface and underground mining for coal, road construction, domestic development, and other human-based perturbations.) Evaluation of the impacts of surface coal mines on the aquatic resources in the Appalachian region of Virginia therefore focused on such streams. Knowledge of the functional components and temporal dynamics of these streams in their natural state has not previously been adequately described to project the changes to be expected under disturbed conditions.

Through intensive investigation of a near-natural state stream and two similar, but surface mining-impacted streams, this study seeks to:

(1) describe the natural seasonal dynamics of: selected physical and chemical parameters; the taxonomic composition, abundance, and biomass of fish and benthic invertebrates; and the organic and inorganic material standing crop;

(2) determine the causes of any differences in the above-mentioned parameters in two mining-impacted streams as compared to a natural system;

(3) determine the variability in the above-mentioned parameters between two mining-impacted streams;

(4) identify, when possible, the interactions between the physical-chemical parameters and biotic populations;

(5) determine the degree of lotic recovery following reclamation treatment of mined areas within a single watershed; and

(6) identify important components for measurement in impact assessment, especially when under temporal and financial constraints.

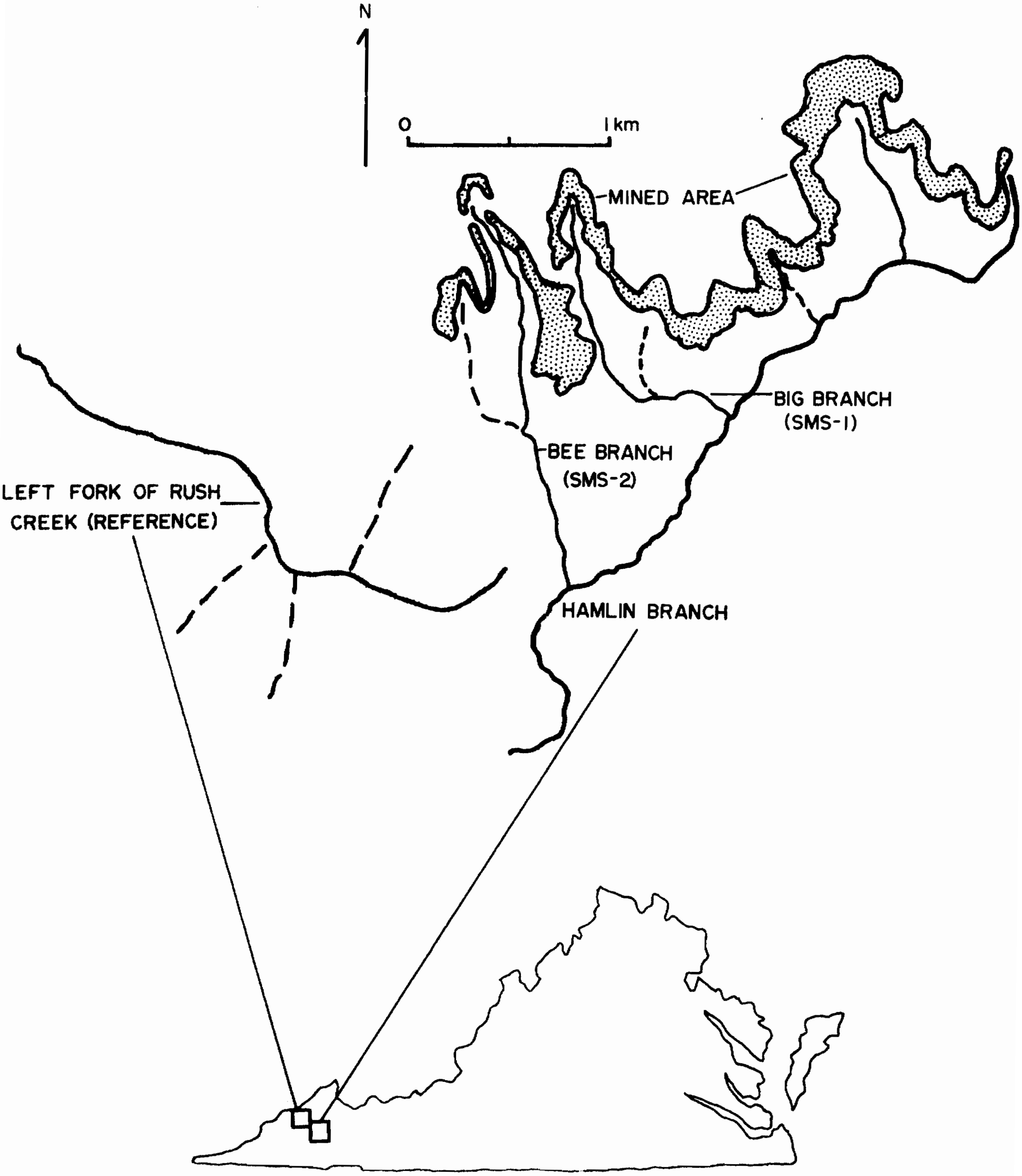
STUDY AREA

Left Fork of Rush Creek (Reference Stream)

The Left Fork of Rush Creek, located in Dickenson County near Clintwood, Virginia, was selected as a near-natural state headwater stream or "reference" stream (Fig. 1). It lies within the Cumberland Plateau Geomorphic Province which is sufficiently dissected in the study area to be mountainous (Dietrich 1970). Pennsylvanian sandstone and shale underlie the area and bear extractable deposits of coal and natural gas.

The Left Fork of Rush Creek drains into the Ohio River via the Cumberland basin. The watershed covers approximately 400 ha, a majority of which is forested with some pastureland. A single dwelling was situated immediately above the sampling stations, but was abandoned after the flooding in spring 1977. The mean gradient from the source to the sampling sites was 49.2 m/km over a distance of 4265 m. Although topographic maps indicated three short permanent tributaries flowing into the Left Fork of Rush Creek, they were found to be intermittent under the low flow conditions experienced during the study period. The substrate was dominated by boulder to cobble-sized particles, and riparian vegetation provided abundant shading. Mean stream width was 140 to 180 cm. Interspersed between riffles, runs, and small pools, were large pools, (average width of 180 to 230 cm and maximum depth of 60 to 80 cm) generally extending into undercut banks. Stream discharge was highly variable, as indicated by measurements at the time of sampling (Table 1). The large substrate size coupled with the sometimes steep gradient permitted substantial subsurface flow.

Fig. 1. The study streams: Left Fork of Rush Creek, located in Dickenson County, Virginia, and Big Branch and Bee Branch, located in Russell County, Virginia. Sampling sites were established near the terminus of each stream.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1 km
MINED AREA
BIG BRANCH (SMS-1)
BEE BRANCH (SMS-2)
LEFT FORK OF RUSH CREEK (REFERENCE)
HAMLIN BRANCH

Table 1. Stream discharge measurements (m^3/min), taken monthly from June 1976 through August 1977 for three southwest Virginia headwater streams.

Date	Reference Stream	SMS-1	SMS-2
6/76	2.16	2.85	3.09
7/76	0.16	0.29	0.08
8/76	0.09	0.06	0.05
9/76	0.93	0.55	0.28
10/76	1.19	1.72	0.68
11/76	1.34	0.60	0.50
12/76	2.08	--	--
3/77	3.23	1.06	0.83
4/77	5.33	1.98	1.30
5/77	0.98	0.85	0.82
6/77	1.30	1.08	0.55
7/77	0.60	0.37	0.34
8/77	0.72	0.48	0.49

Recorded values represent only surface flow. Throughout the text, the Left Fork of Rush Creek will be referred to as simply, the "reference stream".

Big Branch (Strip Mine Stream-1) and Bee Branch (Strip Mine Stream-2)

Big Branch and Bee Branch of Hamlin Branch Creek, located in Russell County, southeast of Dante, Virginia, are first-order streams whose watersheds have undergone disturbance through contour surface mining for coal. The watersheds of both streams are within a much larger area of a single mining operation (Fig. 1) which was completed by 1970. The disturbed area had undergone reclamation treatment between 1970 and 1973 according to Virginia mined-land reclamation laws. Treatment included grading of soil onto the bench and hydroseeding of the bench and outslope with Sericea Lespedeza (*Lespedeza cuneata*).

The study area lies just within the Gulf of Mexico Basin section of the Valley and Ridge Geomorphic Province. The rocks which underlie this province range in age from about mid-Cambrian through early Mississippian (Dietrich 1970). The Cambrian and Silurian-Ordovician deposits are primarily limestone, shale, and sandstone, while the coal-bearing rock is on the periphery of the same Pennsylvanian and Mississipian rock associated with the reference stream area.

Both of the Hamlin Branch tributaries are in the Clinch River drainage, and their waters flow to the Ohio River via the Tennessee River. The Big Branch watershed is approximately 120 ha and the Bee Branch watershed is approximately 130 ha, with a little over 12 percent of the area disturbed by surface mining in the former and 9 percent in the latter. As a result of corporate ownership, no dwellings existed above the sampling sites, although a very limited amount of pasturing was carried on in the lowest part of the valleys. Below and above the band of mining disturbance the land was heavily forested. The bench supported a good coverage of Sericea lespedeza (Lespedeza cuneata), planted in the reclamation program. A line of bare ground did exist on the bench, created by the remnant haul-road running along its center. The outslope, formed by the deposition of spoil and overburden material downslope off the bench, had a number of bare areas and erosional gullies but did support Sericea lespedeza, shrubs, and small trees.

The mean gradient from the source to the sampling sites was 57.7 m/km over a distance of 1830 m for Big Branch and 54.9 m/km over 2010 m for Bee Branch. The substrate of both streams was dominated by boulder to cobble-sized particles; however, much of the rock surface, interstitial spaces, and pool bottoms were covered with a layer of fine sediment of varying thickness. Riparian vegetation provided abundant shading. Mean stream width was 110 to 160 cm with mean depth of 5 to 15 cm for both streams. Riffle and run areas were separated by small pools. Larger pools were much shallower than those in the reference stream and were filled with thick deposits of sediment. Stream discharge, measured exclusively as surface flow, was quite variable (Table 1) and the streams were observed to respond rapidly to precipitation. In the text Big Branch will be referred to as SMS-1 (strip mine stream-1) and Bee Branch will be referred to as SMS-2 (strip mine stream-2).

TECHNIQUES AND PROCEDURES

Sampling included abiotic as well as biotic parameters. Abiotic parameters included several water quality measures, the quantity and composition of fine-particle sediment and suspended solids, the standing crop of large-particle organic material (LPOM), and the quantity of LPOM carried in the water column. Biotic parameters included estimates of the standing crop of Aufwuchs, benthic invertebrates, and fish.

Sampling Schedule

Quarterly sampling began in September 1975 for fish and benthic invertebrates in the reference stream in conjunction with an ongoing evaluation of the impacts of abandoned strip mines on headwater streams in southwest Virginia. Beginning in December 1975, benthic invertebrates were also collected from SMS-1 and SMS-2 on the same quarterly schedule applied to the reference streams. In June 1976 sampling was expanded to include fish, benthic invertebrates, Aufwuchs, fine-particle inorganic sediment, fine and coarse-particle organic matter, and selected water chemistry parameters for all study streams each month.

Weather conditions rendered the mining-impacted streams inaccessible in December 1976 and January 1977, and no samples were collected in January 1977 from the reference stream. Unusually cold temperatures and low precipitation in February 1977 caused the mining-impacted streams to freeze solid to the substrate so that the small amount of water which was able to flow during daylight hours actually ran across the surface of the frozen stream. Shallow riffles were frozen and pools were ice-covered in the reference stream during this same period. No samples were collected from any of the study sites during February 1977.

Monthly sampling resumed in March 1977 and was conducted through August 1977. Table 2 presents the actual dates of sampling. In all additional tables, figures, and text the sampling periods will be indicated by month and year designations only.

Data Collection

Water Quality

Certain water quality parameters have been reported to be particularly sensitive to watershed disturbances such as strip mining; these included alkalinity, conductivity, hardness, pH, and sulfate. These and other measures were monitored throughout the study period.

Water samples collected in the field were analyzed in the laboratory for total alkalinity, total hardness (EDTA), pH, and sulfate following standard procedures (APHA 1975). Water temperature was determined with a mercury field thermometer, conductivity with a YSI Model 33 conductivity meter, and dissolved oxygen was measured in the field using the Hach procedure (Hach Chemical Company 1975). The remoteness of study sites made continuous monitoring of chemical parameters impractical, thus all data represent point-in-time measurements.

Particulate Matter

Particulate matter in streams may be distinguished by size, organic and inorganic composition, and by whether in transport or at rest on the stream bed. Each of these criteria was used in defining several categories of particulate matter, as described below.

Table 2. Dates of quarterly and monthly sampling conducted on three headwater streams in southwest Virginia.

Year	Month	Day
1975	September	15-17[1]
	December	11-14
1976	March	15-17
	June	1-3
	July	7-8
	August	17-18
	September	16-17
	October	15-16
	November	22-23
	December	16[1]
1977	March	17-19
	April	23-24
	May	28
	June	28
	July	21
	August	26-27

[1] Only the reference stream sampled on this date.

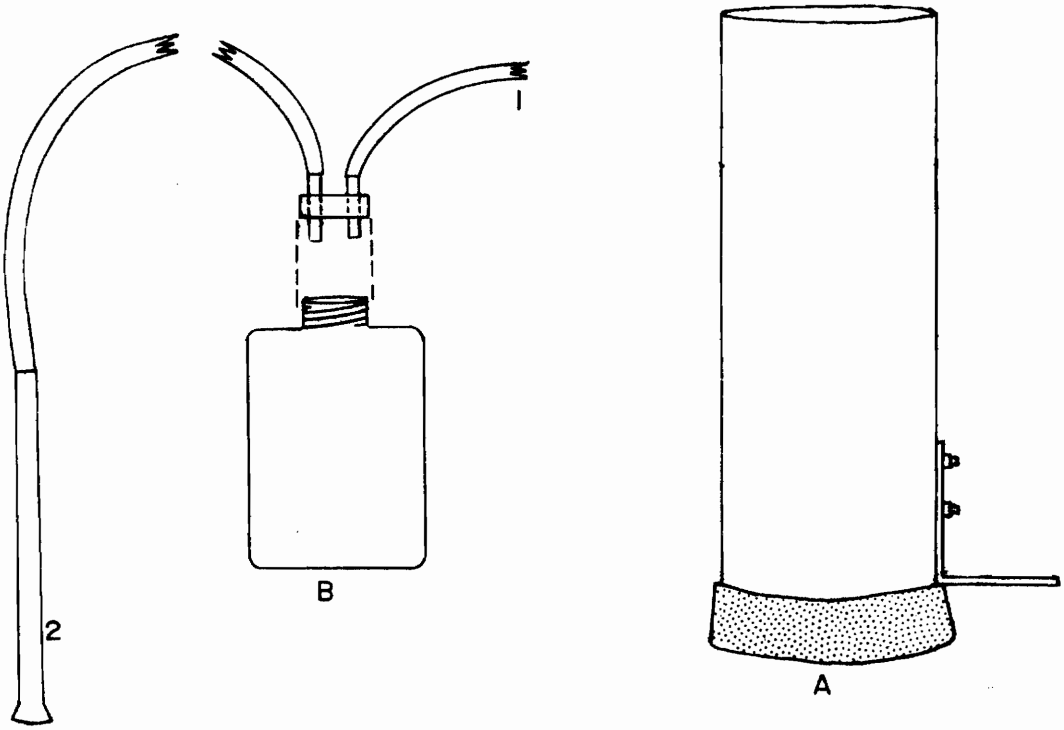
Benthic materials. Benthic material may be partitioned into fine-particle and large-particle fractions. The fine-particle fraction represents a mixture of material wich is organic in nature, and therefore may be of food value to some organisms, and material which is inorganic and acts in habitat degradation. Organic large-particle benthic material, primarily allochthonous inputs, is also an important invertebrate food source. Thus, the following three categories of benthic material were distinguished (shown with their associated acronym used throughout the text):

(1) benthic fine-particle inorganic material (benthic FPIM)
(2) benthic fine-particle organic material (benthic FPOM)
(3) benthic large-particle organic material (benthic LPOM).

Benthic fine-particle inorganic material (FPIM). Preliminary observations indicated that the impacted streams were subject to a greater load of benthic FPIM than the reference stream. A simple and rapid method was developed to quantify bottom sediment load and its inorganic and organic material content.

A Nalgene hand-operated vacuum pump #6131 was attached to an air-tight 1 ℓ collection bottle (Fig. 2). Sufficient pressure could be maintained to raise silt, sand, and even small stones from the stream bottom via a collection tube leading from the sample bottle. A 7 cm i.d. steel cylinder, enclosing 38.5 cm^2 and fitted with a foam ring at its base (Fig. 2), was held against the stream bottom as material was removed from the enclosed area. Sampling was terminated when the water held within the cylinder had been evacuated three times or until 1 ℓ of water had been collected, whichever occurred first. Three such

Fig. 2. Steel cylinder with foam ring (A) used to enclose an area of substrate for sediment removal, and the silt collection bottle (B) with the site of attachment to a hand-operated vacuum pump (1) and the collection tube (2).


1
2
B
A

samples were taken from riffle/run areas in each stream each sampling period. Samples were preserved in 10 percent formalin and left undisturbed in the laboratory for at least four weeks to permit settling. A majority of the preservative was drawn off after this period, prior to drying and ashing. Each sample was then filtered through 450 μm mesh screen to eliminate particles larger than the silt-sized fraction and brought to a volume of 300 to 500 ml with distilled water for subsampling. While samples were vigorously agitated on a magnetic stirrer, placing all but the very heaviest particles in suspension, ten 10 ml aliquots were drawn from successive levels of the agitated mixture, including one aliquot drawn with the pipet in contact with the bottom of the sample container. Aliquots were pooled to form one 100 ml subsample representative of the particle size and composition of the original sample. Pooled samples were dried at 50 C, weighed to determine dry weight, ashed in a muffle furnace at 500 C for 2 h, rehydrated, dried for 24 h at 50 C, and reweighed to determine ash weight (Weber 1973, APHA 1975). Ash weights represented the amount of benthic FPIM per 100 ml subsample. The quantity of benthic FPIM in the original sample was determined by multiplying the ash weight per 100 ml by the original sample volume divided by 100.

Benthic fine-particle organic material (FPOM). The difference between the dry weight and ash weight of fine-particle material as determined above, yields an ash-free dry weight estimate of benthic FPOM. However, examination of benthic materials revealed the presence of coarse and fine-particle coal fragments in the surface mine impacted streams. Assuming that elemental carbon is not as easily colonized or degraded by stream microbes, and is neither as readily ingested or broken down by invertebrate consumers as is leaf and twig litter, the ash-free dry weight estimates of organic material content were certainly over-estimates of usable organic energy for the impacted streams. Thus, a modification of the sugars and related substances test of Dubois et al. (1956), as described below, was used as a second estimate of FPOM in the mining-impacted streams.

Dubois et al. (1956) found that the rapid delivery of a relatively large quantity of concentrated sulfuric acid to dilute sugar solutions in the presence of phenol produced an orange-yellow color, the intensity of which could be directly related to the concentration of sugar in the solution. They also described how standard curves could be constructed from known concentrations of known sugars and used to determine unknown concentrations of these same substances.

A suspension of FPOM would be reduced to a solution of simple sugars and other substances with the rapid delivery of concentrated sulfuric acid and its associated heat generation (pers. comm., Dr. E. Gumm, Department of Biochemistry, Virginia Polytechnic Institute and State University). In the presence of dilute phenol these sugars would also yield an orange-yellow color, although the actual sugars present and their concentrations would be unknown. However, since the ashing procedure yielded adequate estimates of organic content in the reference stream samples which contained no coal fragments, the intensity of the color produced could be associated with a specific concentration of organic material, as determined by the ashing procedure. Using the reference stream samples, a "standard curve" was constructed for each sampling period, relating color intensity to organic material concentration. The intensity of the orange-yellow color produced in the impacted stream samples following the sulfuric acid/phenol treatment was then associated with a specific concentration of organic material, exclusive of coal inclusions, based on the reference stream "standard curve." This procedure assumes that the FPOM was of similar type and origin among streams, that the relationship between organic material concentration and concentration of testable sugars produced was constant among streams, and that agents causing test interferences were similar among streams.

To construct the standard curve, an 11.12 ml subsample, the "blowout volume" of a 10 ml pipet (i.e., a 10 ml pipet filled to the zero mark and emptied completely), of each reference stream silt sample was drawn and diluted to 100 ml. Two replicate aliquots of three different volumes, ranging from 0.25 to 2.00 ml, were placed in thick-walled Kimax tubes and brought to 2 ml with distilled water. This procedure always produced an adequate range of concentration of testable material. One milliliter of 5 percent phenol was added to each sample tube, followed by the rapid delivery of 5 ml of concentrated sulfuric acid to the surface of the liquid sample with constant stirring on a vortex stirrer. The combination of powerful acidification and rapid heat generation reduced organic materials, such as cellulose, to constituent sugars, yielding the characteristic orange-yellow color in the presence of phenol. Color intensity was measured with a Bausch and Lomb Spec 20 spectrophotometer at 487 nm. Absorbance readings were plotted against the known organic material concentrations in the reference aliquots.

Two replicates of two aliquots of different volume of each impacted stream silt sample dilution were similarly treated. Using the reference stream-based standard curve for each sampling period, the colorimetric readings for the mining-impacted streams were indicative of a specific organic material concentration, which when corrected for dilutions, yielded another estimate of benthic FPOM, exclusive of coal inclusions.

Benthic large-particle organic material (LPOM). As part of the benthic invertebrate sampling procedure described later in this section, benthic LPOM was also collected from the sample area and pooled over three depletion runs at two sampling sites on each stream. After removal of benthic invertebrates, this material was divided by visual inspection into two size classes, greather than 5 cm diameter, and 450 μm to 5 cm diameter. These size classes were chosen because they seemed to reflect the point (5 cm dia.) at which a substantial proportion of the leaves collected would exhibit some degree of physical degradation. This did not hold true for buds, inflorescence, catkins, etc., which normally were less than 5 cm in diameter whether they had undergone any degradation or not. The larger particles were removed from the samples by hand, while the smaller particles were separated from the sand and gravel by careful elutrition. Particular care was taken with samples from the mining-impacted streams to exclude fine coal particles collected from the stream bottom with other materials. Benthic LPOM in each size class was dried at 50 C for 48 h, weighed to obtain dry weights, ashed at 500 C for 2 h, rehydrated, dried, and reweighed to procure ash weight for calculation of ash-free dry weight.

Suspended materials. Suspended materials were those in transport in the water column. Suspended materials were also partitioned into fine-particle and large-particle fractions, similar to the benthic materials, so that the following categories were distinguished (shown with their associated acronym used throughout the text):

(1) suspended fine-particle material (suspended FPM)

(2) suspended large-particle organic material (suspended LPOM).

Suspended fine-particle material (FPM). Two 300 ml water samples were collected at mid-stream and mid-depth from each stream in each sampling period to determine suspended fine-particle densities. In the laboratory, samples were filtered through 450 μm mesh screening to eliminate particles larger than the silt-sized fraction and were filtered through predried, tared paper filter discs (Whatman qualitative #5). The filter discs were dried at 50 C for at least 24 h, placed in a dessicator for 30 min, and weighed on a Mettler PN 163 balance to obtain dry weight. Inorganic material content of the suspended fine particles could be assumed to form a fraction comparable to that determined for the bottom load of fine-particle sediment, as described above, since the benthic fraction acts as a reservoir for the suspended fraction.

Suspended large-particle organic material (LPOM). Suspended large-particle organic material was collected with drift nets, 15 cm X 15 cm X 145 cm, constructed of 450 μm screening on a brass rod frame similar to the design of Waters and Knapp (1961). Nets were secured to the stream bottom and left in position from two to four daylight hours at each stream. Water depth and velocity were recorded at the mouth of the nets at the initiation and end of the collection period to calculate the water volume sampled.

Collected materials were preserved in 10 percent formalin. In the laboratory, samples were processed exactly as those collected for benthic estimates, described earlier, except that the separated materials were not ashed. Ash content was assumed to be the same as that determined for benthic LPOM.

Aufwuchs

Measured surface areas of stream rocks, totalling at least 100 cm^2, were scraped with a stiff-bristle brush and rinsed with water until clear of attached materials. Collected material was preserved in 10 percent formalin. Two samples were taken at each study stream in each sampling period. In the laboratory the samples were allowed to stand for approximately three weeks to permit settling. A major part of the preservative was drawn off and replaced with distilled water. A minute subsample (less than 0.5 ml) was drawn from each sample to identify major algal forms and to make a visual estimate of the relative abundance of other materials. The remainder of the sample was inspected under a microscope for benthic invertebrates and large particles of organic debris which were removed. Samples were then dried at 50 C to a point of visible "dryness" followed by an additional 24 h of drying, weight determination on a Mettler PN 163 balance, ashing at 500 C for 2 h, rehydration, redrying for 24 h, and reweighing to determine ash-free dry weight.

Benthic Invertebrates

Two benthic invertebrate samples were collected from each stream in each sampling period. As noted previously, the mining impacted streams had fewer large pools than the reference stream, thus only riffle/run areas which were similar among streams, were sampled for invertebrates in all streams. Samples were collected with a modified circular depletion sampler (Carle 1976), similar in design to that of Waters and Knapp (1961). The sampler enclosed a 0.26 m^2 area of substrate which was disturbed by hand for 60 s. The invertebrates subsequently swept into the collection bottle at the caudal end of the sampler, fitted with 450 μm mesh screen, were removed and preserved in 50 percent isopropyl alcohol. Without moving the sampler, this same action was repeated twice, resulting in three samples suitable for use in depletion methods of population estimation. Following sorting under 10X to 30X magnification, invertebrates were identified to the lowest practical taxon and enumerated. Population estimates were made for each taxon using the weighted maximum likelihood removal technique of Carle and Strub (1978). These estimates were summed for a given sampling station within a sampling period to yield a total benthic density estimate for the station.

Invertebrate taxa were blocked into five trophic groups; collector-gatherers, collector-filterers, predators, scrapers, and shredders; according to Cummins (1973), Hilsenhoff (1975), and Merritt and Cummins (1978) (Appendix Table 1). These trophic groups were used in further numerical analyses and wet-weight biomass determinations for each sample site within a given period. Pooled trophic group samples were dried at 50 C for 48 h to yield a dry weight conversion from wet weight. A separate conversion was calculated for crayfish alone and all other invertebrates combined. Crayfish were not efficiently sampled by the gear and differed greatly in body size and structure as well as in exoskeletal thickness from all of the other invertebrates collected. Therefore, the decapods were not included in biomass analyses. The wet-weight to dry weight conversion for all of the other invertebrates combined was 0.144.

An information theory-based diversity index, Brillouin's H, was calculated for each stream in each sampling period, based on a pooled sample composed of the two invertebrate collections from each stream. Pielou (1966) gives Brillouin's formula as:

$$H = \frac{1}{N} \log \frac{N!}{N_1!\, N_2! \ldots N_s!}$$

where N is the total number of individuals, s is the number of species, and N_i is the number of individuals in the *i*th species. Pielou recommends this procedure for collections not too large for all members to be identified and counted. Logarithms of base 10 were employed.

Fish

Two 30 m sections, separated by at least a 30 m buffer zone, were sampled by DC electrofishing with a Georator generator or a Coffelt backpack electrofishing unit in each stream each period. Each section was isolated from the remainder of the stream by the placement of block nets, and three depletion sampling runs were made. Abundance and biomass determinations were kept separate for each run and for each species. Fish were released upon completion of sampling.

Population estimates for each species were made using the weighted maximum likelihood removal estimation technique of Carle and Strub (1978). Biomass estimates were generated by calculating the mean weight per individual for a given species based on the number and weight of that species actually captured and then multiplying this value by the population estimate for that species. Abundance and biomass estimates were summed over all species for a given sampling section on a given date to yield a total estimate for the section. Abundance and biomass estimates were also corrected to a standard unit of stream surface area of 50 m^2, and further analyses were based on these data.

Meteorological Data

Selected meteorological data for the study were obtained from the report, Climatological Data: Virginia, published monthly by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Asheville, North Carolina.

The nearest recording station was located at the John W. Flannagan Reservoir in Dickenson County, approximately 15 km from the reference stream and 30 km from the mining-impacted streams. Data from this station were used as an indicator of climatic conditions in the study stream areas.

Data Analysis

The primary consideration in the choice of statistical procedures is the appropriateness of the analysis to the data at hand. This will be determined, to a large degree, by the ability to satisfy the assumptions underlying a given procedure.

Parametric statistical procedures generally assume that data follow a specific distribution, usually the normal distribution, and that only the population mean and/or variance are unknown. Violation of these assumptions and that of homogeneity of variance can lead to erroneous interpretation of research results (Pirie and Hubert 1977; Saul et al. 1978).

Nonparametric statistical procedures maintain desirable statistical properties under less rigorous assumptions than for parametric procedures (Hollander and Wolfe 1973). In addition, nonparametric procedures are usually only slightly less efficient than their parametric counterparts under conditions of normality, while generally being far more appropriate when the normality assumption is violated.

The data collected in this study, as in almost any such effort, is not truly normal. More importantly, the variances associated with specific parameters were found to be significantly different among streams as indicated by the F_{max}-test for homogeneity of variance (Sokal and Rohlf 1969). Therefore, nonparametric procedures are used for most data interpretation in this study. The procedures most commonly employed are Friedman's Rank Sum test for randomized blocks, a two-way layout procedure analogous to two-way ANOVA which allows blocking across some factor such as time, and Wilcoxon's Signed Ranks test. These and other nonparametric procedures are described in Hollander and Wolfe (1973). Table 3 specifies the statistical test used for a given data set. Blocking for Friedman's and Wilcoxon's

Table 3. Statistical procedures applied to analyze various data sets for three headwater streams in southwest Virginia.

Data Set	Friedman's Rank Sum	F_{max}-test	Other Tests
Water Quality Parameters	X	X	
Hardness and Cumulative Precipitation			Spearman's Rank Correlation
Sulfate and Cumulative Precipitation			Spearman's Rank Correlation
Density of Benthic FPIM	X	X	
Density of Benthic FPOM	X	X	
Percentage of Benthic Fine-Particle Material which was Organic	X		
Difference in Percentage Organic Content by Ash and Colorimetric Procedures			Wilcoxon's Signed Ranks
Density of Benthic LPOM	X		
Percentage of Benthic LPOM > five centimeters diameter	X		
Density of Suspended Fine Particles	X	X	
Density of Suspended LPOM	X		
Percentage of Suspended LPOM > five centimeters diameter	X		
Density and Percentage Organic Content of Aufwuchs	X		
Benthic Invertebrate Density Estimates	X		
Benthic Invertebrate Biomass Estimates	X		

Table 3. Statistical procedures applied to analyze various data sets from three headwater streams in southwest Virginia (continued).

Data Set	Friedman's Rank Sum	F_{max}-test	Other Tests
Benthic Invertebrate Trophic Composition			
(1) by density	X		
(2) by percentage	X		
Benthic Invertebrate Taxonomic Composition			
(1) by density	X		
(2) by percentage	X		
Fish Density Estimates	X		
Fish Biomass Estimates	X		

tests was always across sampling periods (i.e. time) so that the test comparisons are made among streams.

RESULTS

Water Quality

Total alkalinity, total hardness, and sulfate were significantly higher ($p<.04$) in SMS-1 than in SMS-2 and these same parameters were significantly higher ($p<.04$) in the impacted streams than in the reference stream (Table 4). Although alkalinity is reported as total alkalinity, the titrimetric analyses indicated that only the bicarbonate ion (HCO_3^-) was of practical importance in the buffering systems of these streams.

The variances associated with sulfate and hardness data were found to be significantly different among streams ($p<.01$). The greater variability in the data from mining-impacted streams is reflected in the standard error values (Table 4). Alkalinity and pH exhibited homoscedasticity.

All water quality parameters underwent little temporal variation in the reference stream, while broad changes occurred for sulfate and hardness in the mining-impacted streams over the study period. No seasonal patterns were apparent. Fluctuations were not related in a simple fashion to rainfall, with correlation between sulfate and cumulative precipitation for four days and four weeks prior to sampling, and hardness and cumulative precipitation over the same periods indicating virtual independence between these factors. Sulfate and hardness values did, however, tend to vary together in SMS-1 ($r = .57$, $p<.025$), and SMS-2 ($r = .71$, $p<.01$).

Mean pH was calculated by converting pH values to the appropriate hydrogen ion concentration, averaging these values, and expressing the

Table 4. Mean total alkalinity, total hardness, pH, sulfate, and associated standard errors (n = 12). Underlined values are not significantly different from each other ($p > .05$).

Parameter	Reference Stream	SMS-2	SMS-2
Mean Alkalinity (mg/1 $CaCO_3$)	13.17 ± 1.19	22.00 ± 1.84	28.67 ± 1.76
Mean Hardness (mg/1)	28.08 ± 2.29	296.17 ± 27.53	512.75 ± 42.97
Mean pH	7.18	6.54	6.53
Mean Sulfate (mg/1)	7.67 ± 1.18	185.42 ± 16.15	307.33 ± 23.52

average in pH units. Although pH was significantly lower in the impacted streams than in the reference stream ($p<.01$), it was not significantly different between impacted streams (Table 4).

Temperature and dissolved oxygen data were used to calculate percentage oxygen saturation, corrected for altitude. After the first nine months of sampling, no significant differences were found in percentage oxygen saturation among streams, with all values falling near the saturation point. No further oxygen determinations were made after May 1977.

Conductivity was measured on two occasions, August and October 1977. Conductance was markedly higher in the impacted streams than in the reference stream (mean conductivity in umhos for SMS-1 of 405, SMS-2 of 272, and reference stream of 40).

Water chemistry measures from the mining-impacted streams were compared to those determined for other headwater streams in the area which were under the influence of surface mines abandoned without reclamation applications between 1955 and 1965 (Maughan et al. 1977). SMS-1 and SMS-2 appeared to be at a comparable water quality status as the ten-year post-abandonment stream, Ambrose Branch (Table 5). The water quality of SMS-1 and SMS-2 reflected greater watershed disturbance than in the twenty-year post-abandonment stream (Short Branch), but not as great a disturbance as in the acid drainage-impacted stream (Keel Branch). The low sulfate, alkalinity, and hardness values in the twenty-year post-abandonment stream (Short Branch) were probably more the result of the very small fraction of the watershed

Table 5. A comparison of the means of selected water quality parameters in the study streams and in other headwater streams in southwest Virginia influenced by abandoned surface mines. Data for abandoned mine streams from Maughan et al. (1977).

Stream	Mean Sulfate (mg/l)	Mean Hardness (mg/l)	Mean Alkalinity (mg/l)
Reference Stream (this study)	8	28	13
SMS-1 (this study)	307	513	29
SMS-2 (this study)	185	296	22
Ambrose Branch (stream draining mine abandoned approx. 1965)	271	333	28
Short Branch (stream draining mine abandoned approx. 1955-1960)	16	35	14
Keel Branch (stream draining mine abandoned approx. 1955-1960, but also receiving acid drainage from underground mine)	451	538	0

disturbed by mining, rather than a product of the long (20 years) recovery period.

Particulate Matter

The percentage of benthic fine-particle material which was organic and inorganic was determined as was the absolute quantity of organic and inorganic material per unit bottom area. The percentage of LPOM in each of the two size classes described earlier, the total density of LPOM on the stream bed and in the water column, and suspended fine-particle density were also determined.

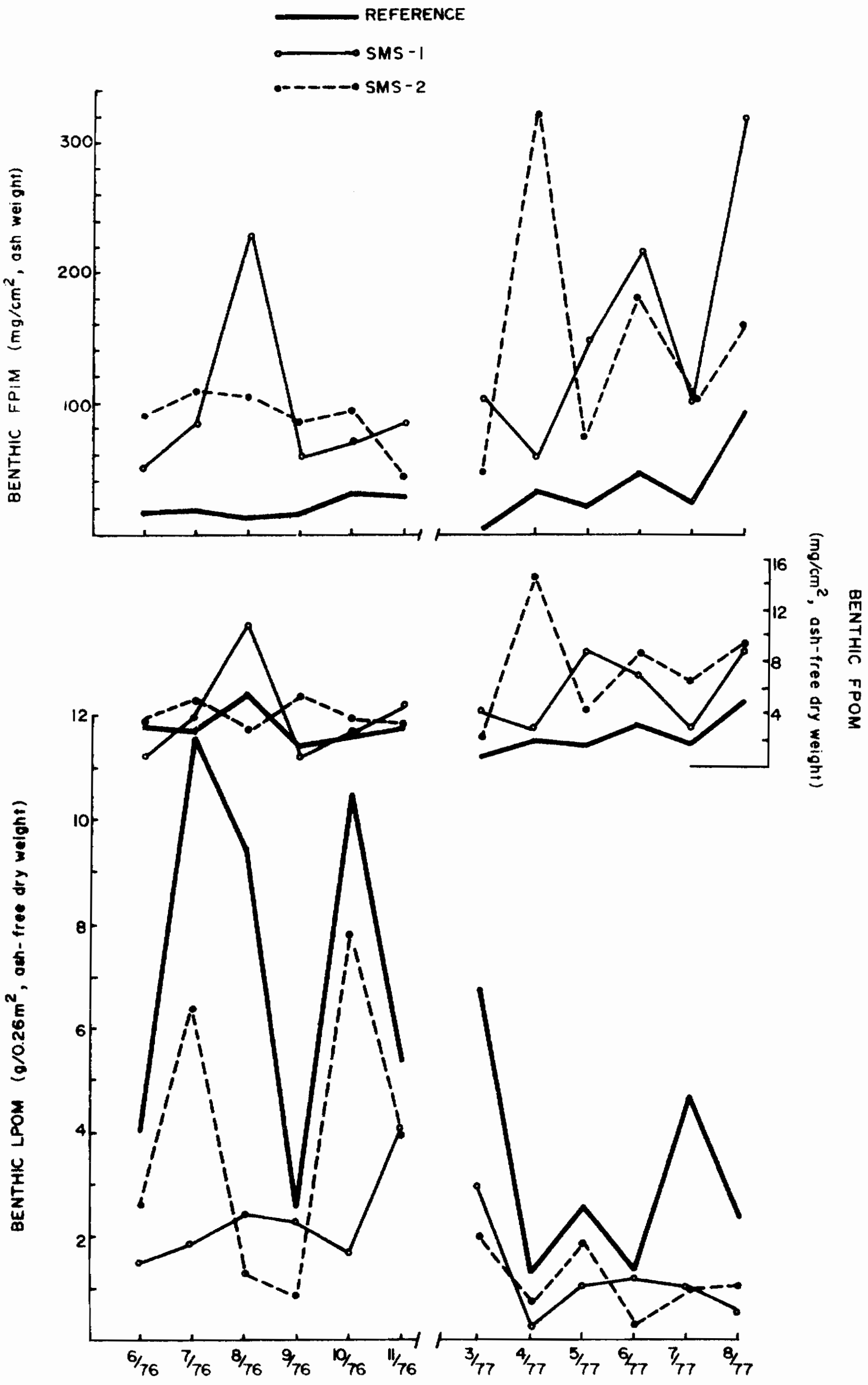
Benthic Materials

Benthic fine-particle inorganic material (FPIM). Inorganic material density (mg/cm^2, ash weight) of benthic fine particle sediment was significantly higher ($p<.01$) in the impacted streams than in the reference stream, but was not significantly different between the impacted streams (Table 6). The variance in benthic FPIM density was also found to be significantly greater ($p<.01$) in the mining-impacted streams than in the reference stream. Benthic FPIM was virtually independent of season in the reference stream, exhibiting a constant low level, although the amount and variability of FPIM increased following flooding in April 1977 (Fig. 3). Changes in benthic FPIM in SMS-1 and SMS-2 did not closely correspond nor was there a clear seasonal pattern (Fig. 3). Changes in the density of benthic FPIM exhibited no consistent relationship to precipitation prior to sampling or to stream discharge. Peaks in FPIM in August 1976 and April, June, and August 1977 occurred at times of high and low discharge,

Table 6. Mean benthic FPIM density, mean percentage organic material content of benthic fine-particle sediment, and mean benthic FPOM density in three headwater streams in southwest Virginia between June 1976 and August 1977. Underlined values are not significantly different from each other ($p > .05$).

Parameter	Reference Stream	SMS-1	SMS-2
Mean Benthic FPIM Density (mg/cm^2, ash wt.)	30.13 ± 5.02	130.1 ± 20.20	119.82 ± 17.46
Mean Percentage Organic Matter by Ash Procedure	11.50	4.00	5.15
Mean Percentage Organic Matter by Colorimetric Procedure	---	3.22	3.16
Mean Benthic FPOM Density (mg/cm^2, ash-free dry weight)	2.82	5.07	5.83
Mean Benthic FPOM Density (mg/cm^2, by colorimetric procedure)	---	3.51	3.20

Fig. 3. Benthic FPIM, benthic FPOM, and benthic LPOM in three southwest Virginia headwater streams from June 1976 through August 1977.


REFERENCE
SMS - 1
SMS - 2
BENTHIC FPIM (mg/cm^2, ash weight)
300
200
100
BENTHIC FPOM (mg/cm^2, ash-free dry weight)
16
12
8
4
BENTHIC LPOM (g/0.26m^2, ash-free dry weight)
12
10
8
6
4
2
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77

high and low four-day rain accumulation prior to sampling, and high and low four-week rain accumulation prior to sampling.

Benthic fine-particle organic material (FPOM). The percentage organic material content of the benthic fine-particle fraction was significantly higher ($p<.01$) in the reference stream than in the mining-impacted streams, based on both the ashing and colorimetric procedures (Table 6). The ash data also revealed a significantly higher ($p<.01$) percentage of organic matter in SMS-2 than in SMS-1, although no such difference was identified by the colorimetric procedure.

The colorimetric procedure yeilded consistently lower estimates of the percentage of the benthic fine sediment which was FPOM in the mining-impacted streams than the ashing technique. The mean difference in the organic fraction as estimated by the two procedures was statistically significant ($p<.01$) between procedures and representing about a 25 percent decline in colorimetric values as compared to the ash data.

FPOM density estimates (mg/cm^2), based on the ashing procedure for the reference stream and the ashing and colorimetric procedures for the impacted streams, were significantly higher ($p<.01$) in the impacted streams (Table 6). Although the ash data revealed no significant difference in total volatile material between SMS-1 and SMS-2, the colorimetric test did. Biases in the latter procedure due to dilutions, incomplete and variable particle breakdown into testable substances, and possible heterogeneity of testable sugars between reference and impacted streams make the ashing procedure more consistent and reliable even though it most certainly yields some degree of overestimation due to the volatilization of coal inclusions.

Benthic FPOM varied little in any of the study streams over sampling periods in 1976 but underwent wide oscillations in the impacted streams in 1977 (Fig. 3). Temporal changes in benthic FPOM correlated more closely with the pattern observed for benthic FPIM than with any other parameter measured, particularly in the impacted streams (reference stream, r = 0.308, $p < .10$; SMS-1, r = 0.846, $p < .001$; SMS-2, r = 0.748, $p < .005$). Peak densities of benthic LPOM were reflected in higher benthic FPOM values in the following sampling period.

Benthic large-particle organic material (LPOM). There was no significant difference in the proportion of benthic LPOM standing crop greater than or less than 5 cm in diameter among streams. The total standing crop (g/m^2, ash-free dry weight) was significantly greater ($p < .01$) in the reference stream than in the mining-impacted streams, although there was no significant difference between the latter (Table 7).

Analysis of dry weight and ash-free dry weight indicated that no single conversion factor could be used to transform one measure to the other across sampling dates since significant differences in the percentage ash were found between periods ($p < .025$).

Almost all surface organic matter was collected during the three benthic invertebrate depletion runs at a single sampling site. However the benthic LPOM was never totally depleted from a site since additional particles were brought to the surface of the substrate with the deeper substrate disturbance of each depletion run. Progressively

Table 7. Mean total standing crop of benthic LPOM, standard error of the mean (n = 24), and mean percentage of benthic LPOM <5 cm in diameter, for three headwater streams in southwest Virginia between June 1976 and August 1977. Underlined values are not significantly different from each other ($p>.05$).

Parameter	Reference Stream	SMS-1	SMS-2
Mean Total Benthic LPOM Density (g/m^2, ash-free dry weight)	20.174 ± 3.159	7.003 ± 1.115	9.664 ± 2.611
Mean Percentage Benthic LPOM <5 cm in diameter	66.0	61.3	74.4

deeper layers of the stream substrate may therefore hold organic material "in store" to be released at some later time. This is certainly an area for further investigation.

Only riffle/run areas were sampled for benthic LPOM. Thus, the organic material estimates recorded in this study must be regarded as underestimates of the mean standing crop for the entire stream since large pools act as organic material traps.

Temporal changes in benthic LPOM were similar in the reference stream and SMS-2 (Fig. 3), with maximum abundance in July and October 1976; however, SMS-1 exhibited a single peak in November 1976. Based on March 1977 estimates, a large proportion of the benthic LPOM available in November 1976 was still available by the latter period. Benthic LPOM dropped sharply in all streams after flooding in April 1977 and generally remained below levels attained the previous year.

Suspended Materials

Suspended fine-particle material (FPM). The density of suspended fine particles (i.e. less than 450 μm in diameter) in mg/l dry weight was significantly greater ($p<.01$) in SMS-2 than in SMS-1 and significantly greater ($p<.01$) in the mining-impacted streams than in the reference stream (Table 8). The variance in the density of suspended fine particles was also significantly greater ($p<.01$) in the mining-impacted streams.

Total suspended material changed relatively little in any of the streams prior to the April 1977 flood (Fig. 4) compared to the benthic load. Post-flood levels were higher in all streams than in the previous year, but these levels declined throughout the remaining

Fig. 4. Suspended fine-particle material and suspended LPOM in three southwest Virginia headwater streams from June 1976 through August 1977.

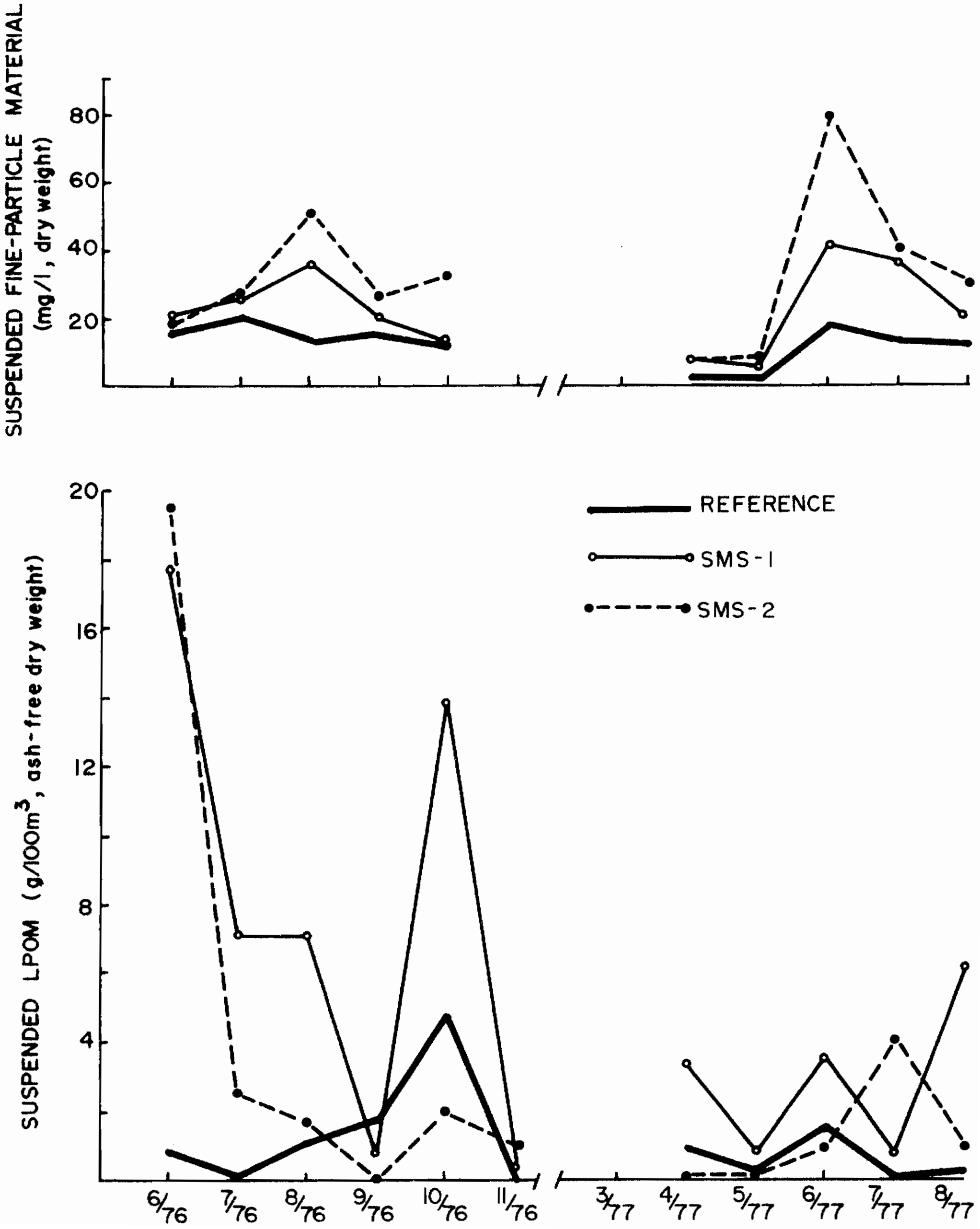

SUSPENDED FINE-PARTICLE MATERIAL
(mg/l, dry weight)
80
60
40
20
SUSPENDED LPOM (g/100m³, ash-free dry weight)
20
16
12
8
4
REFERENCE
SMS-1
SMS-2
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77

Table 8. Mean suspended fine-particle material density and standard error of the mean (n = 20). All values are significantly different ($p<.01$).

Parameter	Reference Stream	SMS-1	SMS-2
Mean Suspended Fine-Particle Density (mg/l, dry weight)	12.64 ± 1.36	23.31 ± 2.74	31.97 ± 4.75

sampling periods of 1977. Although the load of suspended particles was certainly a function of surface runoff and stream discharge, there was no clear pattern between discharge, rainfall, and suspended load estimates over the study period. If the organic and inorganic fraction of suspended fine-particle material is assumed to be comparable to that determined for benthic fine-particle material (i.e. 88 percent inorganic for the reference stream and 95 percent inorganic for the impacted streams), then the abundance and dynamics of suspended fine-particles was dominated by inorganic material throughout the study, especially in the impacted streams.

Suspended large-particle organic material (LPOM). There was no significant difference in the percentage of the suspended LPOM greater than or less than 5 cm in diameter among streams. The total suspended LPOM density (g/100 m^3, ash-free dry weight) was significantly different among streams ($p < .03$), with higher densities occurring in the impacted streams (Table 9).

Changes in suspended LPOM (Fig. 4) were positively associated with stream discharge, where high discharge and elevated LPOM occured together. The autumn peak in benthic LPOM was paralleled by a peak in suspended LPOM; no other seasonal pattern for suspended LPOM was evident.

Aufwuchs

The algal flora of the mining-impacted streams was restricted, almost exclusively, to diatoms, predominated by *Navicula*, *Cymbella*, and *Opephora*. A small number of the filamentous blue-green alga, *Lyngbya*, were found on two occasions. Small fragments of coal were

Table 9. Mean total suspended LPOM density, standard error of the mean (n = 11), and mean percentage suspended LPOM <5 cm in diameter for three headwater streams in southwest Virginia between June 1976 and August 1977. Underlined values are not significantly different from each other (p>.05).

Parameter	Reference Stream	SMS-1	SMS-2
Mean Total Suspended LPOM Density (g/100 m^3, dry weight)	1.281 ± 0.465	6.366 ± 2.020	3.657 ± 1.995
Estimated Total Suspended LPOM Density (g/100 m^3, ash-free dry weight) [1]	1.104 ± 0.417	5.301 ± 1.712	3.083 ± 1.686
Mean Percentage Suspended LPOM <5 cm in diameter	72.2	56.4	67.2

---

[1] Not subject to statistical testing.

also observed among the more abundant fine-particle inorganic sediment mixed with amorphous detritus, which covered the rock substrate.

Although diatoms also predominated in the reference stream samples, many other forms were found, including the filamentous green algae, *Zygnema* and *Stigeoclonium*, *Closterium* and other desmids, and the filamentous blue-green algae, *Anabaena*, *Lyngbya*, and *Oscillatoria*. The diatoms were represented by *Navicula*, *Synedra*, *Cymbella*, *Gomphonema*, *Opephora*, and *Melosira*. The most abundant material in the observational samples was amorphous detritus, with small amounts of fine-particle inorganic sediment.

The percentage organic matter in the Aufwuchs samples, based on ash-free dry weight, was significantly higher ($p<.01$) in the reference stream than in SMS-1 or SMS-2 despite the fact that the two latter estimates included volatilized coal fragments and were thus overestimates. The mining-impacted streams were not significantly different from each other in percentage organic matter (Table 10).

However, total organic material density of the Aufwuchs samples per square centimeter of rock surface was significantly greater ($p<.01$) in SMS-2 than SMS-1 and significantly greater in both impacted streams than in the reference stream (Table 10). This is not to say, however, that either the standing crop or production of the attached community was greater in the impacted streams. The impacted stream rock surfaces were covered with a layer of fine sediment, the same material collected with the vacuum suction device. This material contained substantial amounts of volatile material (Table 6). Thus, especially in the case of the impacted streams, the two measures

Table 10. Mean percentage organic matter content of Aufwuchs samples and mean organic material density in three headwater streams in southwest Virginia between June 1976 and August 1977. Underlined values are not significantly different from each other (p>.05).

Parameter	Reference Stream	SMS-1	SMS-2
Mean Percentage Organic Matter	12.75	4.14	4.38
Mean Organic Matter Density (mg/cm^2, ash-free dry weight)	0.325 ± 0.045	0.513 ± 0.068	1.121 ± 0.315

(i.e. ash-free dry weight of benthic fine-particle sediment and Aufwuchs) may be estimates of a single parameter or are at least inexorably confounded here. Observations indicated that the organic content of the Aufwuchs samples from all streams was made up principally of particles of amorphous detritus plus a limited amount of epilithic/epipelic algae, almost exclusively diatoms. The predominance of detrital particles masked any differences in the algal Aufwuchs contribution to the organic material pool among streams, especially in the impacted streams where relatively large amounts of organic matter were trapped within the heavy sediment deposits. These deposits certainly limited the availability of Aufwuchs material to benthic scrapers. These deposits may also have contributed to the apparent lower algal diversity observed in the impacted streams as compared to the reference stream.

Benthic Invertebrates

The benthic invertebrate community has been evaluated based on five major aspects: 1) taxonomic composition, in terms of specific taxa present, taxonomic diversity, and the frequency-distribution of individuals within the taxa identified; 2) abundance, as measured by numerical density and biomass; 3) trophic composition, as indicated by the distribution of individuals and biomass within five trophic groups; 4) seasonal changes in the above-mentioned parameters; and 5) life history characterization.

Taxonomic Composition

Species level identification was not always practical and/or possible. A complete list of the lowest taxonomic units identified within each invertebrate group and a relative abundance rating for each taxon in each stream is provided in Appendix Table II.

Aquatic insects predominated in the benthos of all study streams, with over 85 percent of the individuals collected belonging to the Ephemeroptera, Plecoptera, Coleoptera, and the Diptera. Non-insect taxa included the Oligochaeta, Nematoda, Hydracarina, two genera of Decapoda, and a single species of Pelecypoda.

Percentage and density comparisons. The percentage of the benthos represented by major invertebrate groups and the density of these major taxa are compared among streams in Tables 11 and 12, respectively.

The proportion of the invertebrate community made up of Ephemeroptera was significantly lower in SMS-1 than in SMS-2, but there was no significant difference between SMS-2 and the reference stream. The mean density of Ephemeroptera (number/0.26 m^2) was significantly greater in the reference stream than in SMS-2 and significantly greater in SMS-2 than in SMS-1.

The proportion of Plecoptera in the benthos was significantly greater in SMS-1 than in SMS-2 and significantly greater in SMS-2 than in the reference stream. However, there was no difference in plecopteran densities between the reference stream and SMS-2, which were significantly lower than in SMS-1.

Coleoptera were infrequently encountered and were never abundant in the mining-impacted streams, and were thus not suitable for statistical treatment. Coleoptera were collected in every sampling period in the reference stream where they constituted a major component

Table 11. Mean percentage of the total benthic density represented by major taxa in three southwest Virginia headwater streams from December 1975 through August 1977.

Taxa	Reference Stream	SMS-1	SMS-2
Ephemeroptera	41.2	8.2**	47.2
Plecoptera	4.4**	29.3**	16.8**
Coleoptera[1]	17.6	0.3	1.5
Diptera	22.2	46.8**	26.4
Trichoptera	2.7**	7.5*	5.5*
Oligochaeta[1]	7.6	4.9	0.7
Total	95.7	97.0	98.1

* significantly different among streams, $p<.05$.

** significantly different among streams, $p<.01$.

[1] not subject to statistical testing

Table 12. Mean density (number/0.26 m^2) of major benthic taxa in three southwest Virginia headwater streams from December 1975 through August 1977.

Taxa	Reference Stream	SMS-1	SMS-2
Ephemeroptera	239.8**	15.5**	172.1**
Plecoptera	16.8	44.3**	24.2
Coleoptera[1]	136.6	0.6	3.2
Diptera	103.9**	150.4**	44.2**
Trichoptera	11.6	12.0	8.8
Oligochaeta[1]	51.4	7.7	1.0

* significantly different among streams, $p<.05$

** significantly different among streams, $p<.05$

[1] not subject to statistical testing

of the benthos.

There was no significant difference in the proportion of Diptera in SMS-2 and the reference stream, but the proportion in SMS-1 was significantly greater than in either of the former streams. All streams were significantly different in mean dipteran density, which was highest in SMS-1 and lowest in SMS-2.

Trichoptera were poorly represented in all streams. They made up a significantly greater proportion of the benthos in SMS-1 than in SMS-2 and a significantly greater proportion in SMS-2 than in the reference stream. However, the density of Trichoptera was not significantly different among streams.

Oligochaetes, also not subject to testing, generally were more abundant and made up a larger proportion of the reference stream benthos than in the mining-impacted streams.

Temporal variation. Temporal variation will be described for only the four most abundant taxa, Ephemeroptera, Plecoptera, Diptera, and Coleoptera.

Ephemeroptera consistently made up 20 to 40 percent of the benthos in the reference stream (Fig. 5), with the largest proportion and the highest densities occurring in June, July, and August of 1976 and 1977. Mayflies formed a large proportion of the benthos in March and April 1977 but actual densities were very low compared to the summer months of both years. Loss of Ephemeroptera due to bottom ice formation and flooding contributed to the low densities. The summer abundance peaks exhibited a different taxonomic composition in the two years (Table 13), with fewer species making major contributions

Fig. 5. Percentage of major taxonomic groups in the reference stream benthos on the basis of density estimates from December 1975 through August 1977.

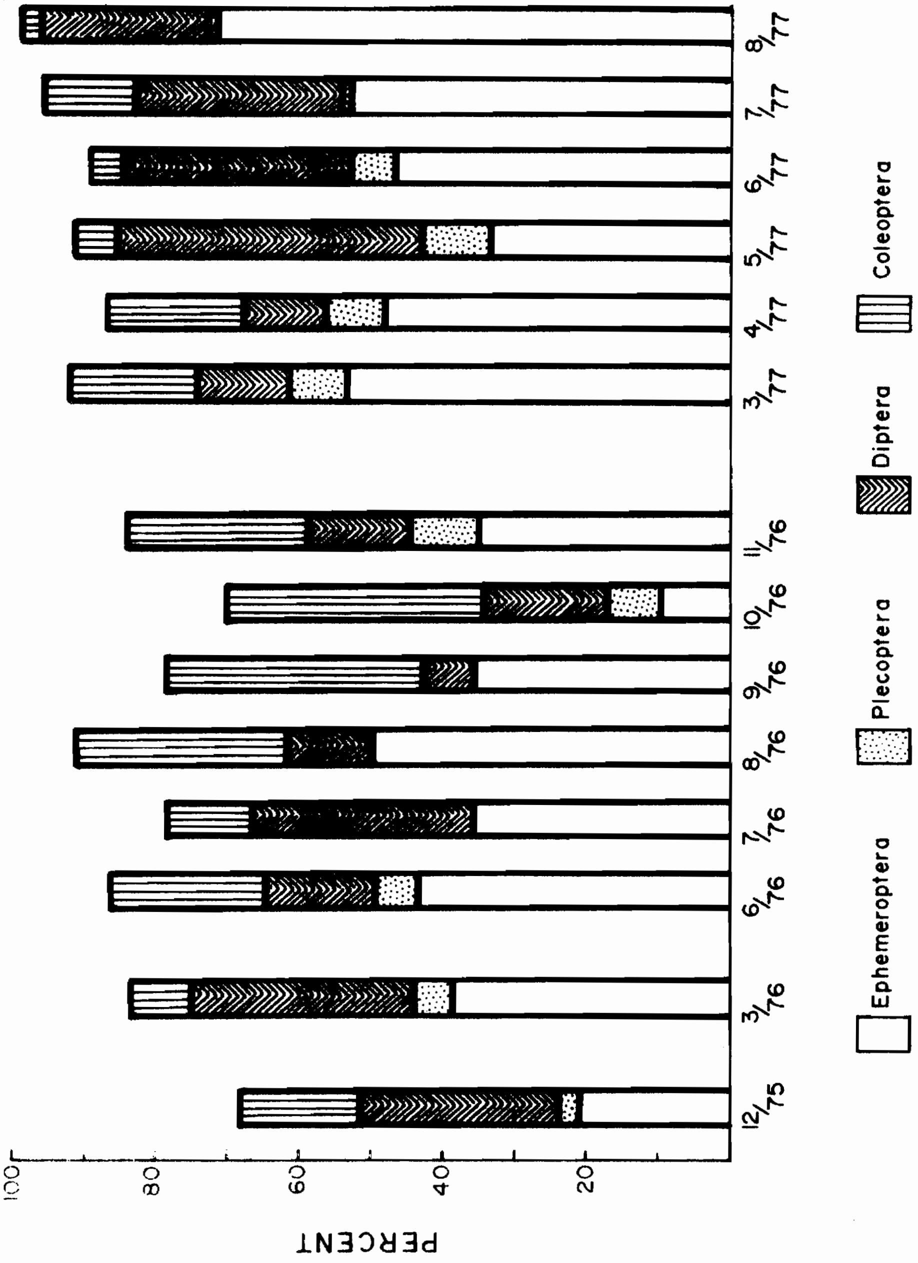

PERCENT
100
80
60
40
20
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77
Ephemeroptera
Plecoptera
Diptera
Coleoptera

Table 13. Predominant Ephemeroptera genera contributing to benthic abundance maxima in the study streams for the listed periods between December 1975 and August 1977. Listings are in order of decreasing abundance.

Date	Reference Stream	SMS-1	SMS-2
6/76	*Heptagenia* *Ephemerella* *Centroptilum*		*Centroptilum* *Baetis*
7/76	*Caenis* *Ephemerella* *Stenonema* *Centroptilum*	*Centroptilum*	*Centroptilum* *Caenis* *Stenonema*
8/76	*Ephemerella* *Ephemera* *Stenonema* *Stenacron*	*Centroptilum* *Ephemera*	*Ephemerella* *Ephemera* *Centroptilum*
9/76	*Ephemerella* *Ephemera*		*Ephemerella* *Ephemera* *Paraleptophlebia*
6/77	*Stenonema* *Centroptilum*	*Centroptilum* *Stenonema*	*Stenonema* *Centroptilum*
7/77	*Stenonema* *Centroptilum* *Ephemera*	*Centroptilum* *Stenonema*	*Stenonema* *Centroptilum*
8/77	*Ephemera* *Stenonema* *Ephemerella* & *Centroptilum*	*Centroptilum*	*Centroptilum* *Ephemerella* *Ephemera*

to the total ephemeropteran density in 1977. Only during the months of March, June, July, and August did Ephemeroptera represent over 5 percent of the benthos in SMS-1 in 1976 and 1977 (Fig. 6). The summer abundance peaks were made up of only one or two taxa and the predominant contributors differed between years (Table 13). Ephemeroptera consistently made up over 25 percent of the benthos in SMS-2 (Fig. 7), with maximum abundance generally following the pattern in the reference stream. In 1976 and 1977 the taxonomic composition of the summer increase in mayflies in SMS-2 was more similar to that in the reference stream than to that in SMS-1 (Table 13).

Both the proportion and density of Plecoptera were highest in March, October, and November 1976 and March 1977 in the reference stream (Fig. 5). Plecopteran densities were reduced to only a few individuals per sample in April 1977. The taxonomic composition was different between the seasonal peaks but similar in the March peak of 1976 and 1977 (Table 14). The proportion and density of Plecoptera were also highest in March, October, and November 1976 and March 1977 in SMS-1 and SMS-2 (Figs. 6 and 7), despite the frozen conditions in February 1977. The taxonomic composition of the peaks was similar in both impacted streams but dissimilar to that in the reference stream (Table 14).

Diptera, primarily Chironomidae and Tipulidae, consistently made up 15 to 25 percent of the reference stream benthos, but the proportion and density varied widely in the impacted streams. Diptera exhibited no clear seasonal pattern in any of the streams (Figs. 5-7). Dipteran density was about 50 percent lower in all streams in March 1977 after

Fig. 6. Percentage of major taxonomic groups in the SMS-1 benthos on the basis of density estimates from December 1975 through August 1977.

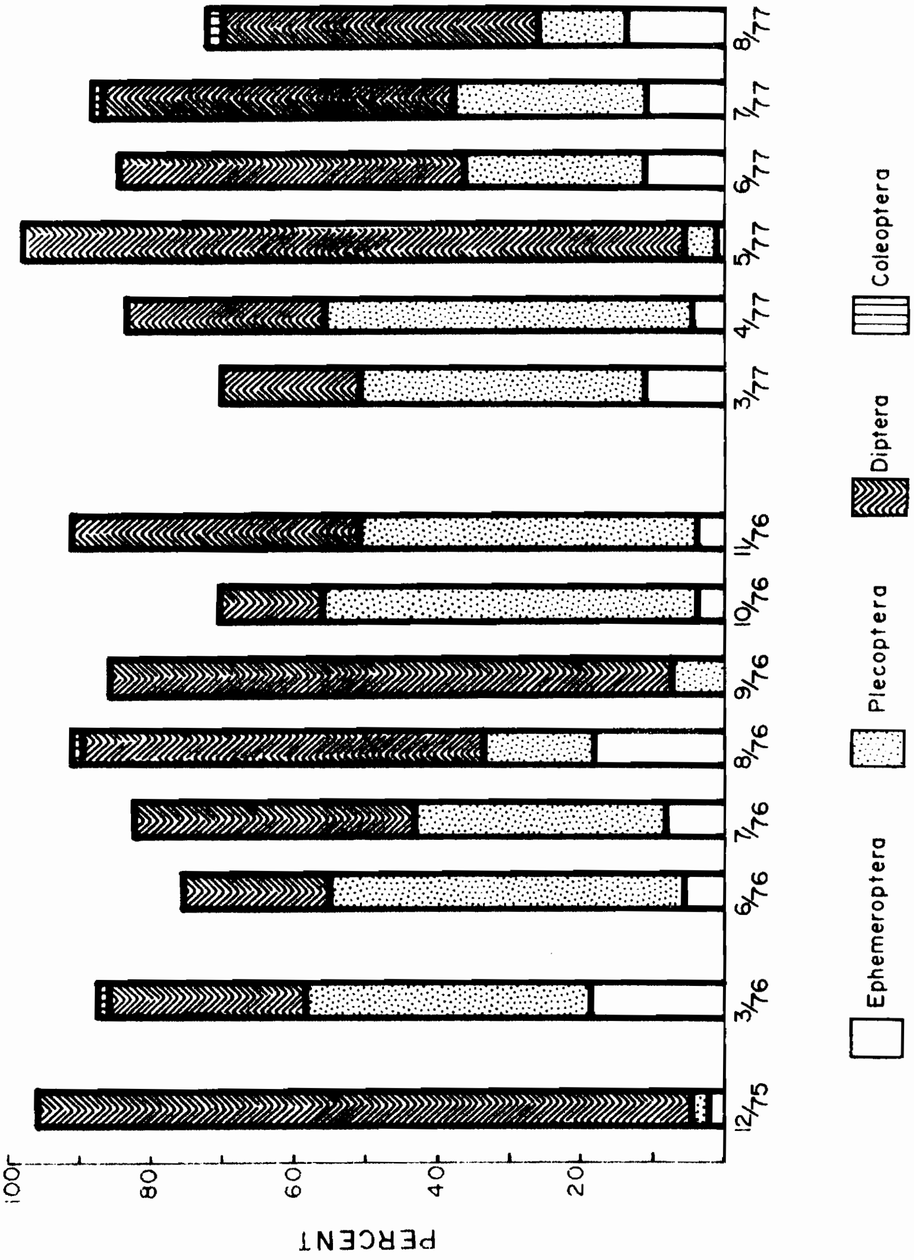

PERCENT
100
80
60
40
20
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77
Ephemeroptera
Plecoptera
Diptera
Coleoptera

Fig. 7. Percentage of major taxonomic groups in the SMS-2 benthos on the basis of density estimates from December 1975 through August 1977.

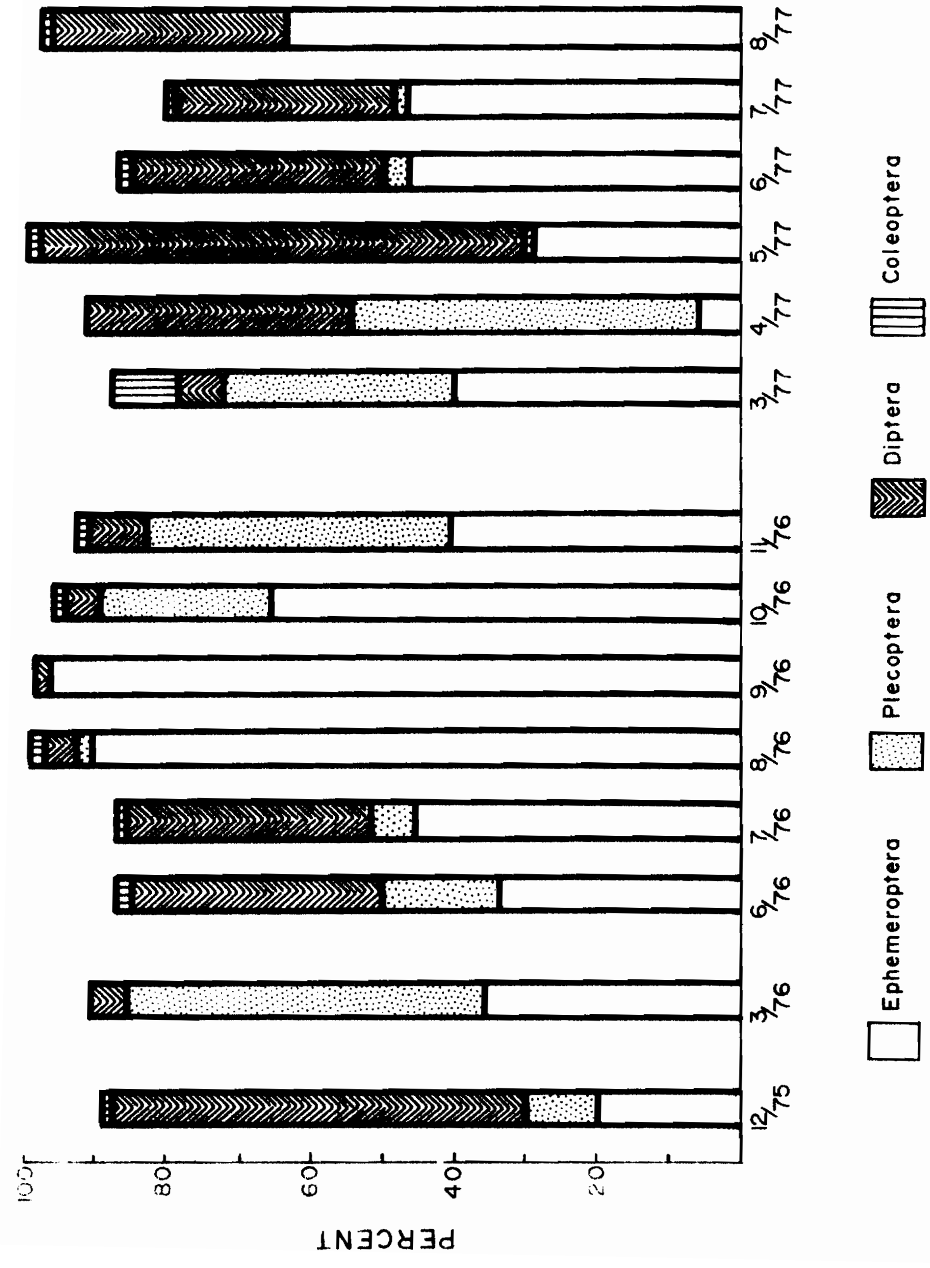

PERCENT
100
80
60
40
20
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77
Ephemeroptera
Plecoptera
Diptera
Coleoptera

Table 14. Predominant Plecoptera genera contributing to benthic abundance maxima in the study streams for the listed periods between December 1975 and August 1977. Listings are in order of decreasing abundance.

Date	Reference Stream	SMS-1	SMS-2
3/76	*Isoperla*	*Amphinemura* *Hastaperla* *Leuctra*	*Hastaperla*
10/76	*Allocapnia* *Nemoura*	*Allocapnia*	*Allocapnia*
11/76	*Isoperla* *Allocapnia*	*Allocapnia* *Nemoura*	*Hastaperla* & *Nemoura* *Allocapnia* *Isoperla*
3/77	*Isoperla*	*Hastaperla* *Nemoura*	*Hastaperla* *Nemoura*

February freezing, than in the previous November. Recovery was relatively rapid for Diptera in all streams, following a drastic drop in abundance after April 1977 flooding.

Coleoptera, primarily Psephenidae and Elmidae, represented a substantial proportion of the benthos in only the reference stream (Fig. 5). No clear seasonal pattern was exhibited, although Coleoptera were sharply reduced in the April 1977 disturbance and showed little recovery through the completion of sampling in August.

Diversity. Taxonomic diversity, in its simplest sense, refers to the number of different, identifiable taxa present in a sample, collection, community, or other defined unit. More commonly, diversity is expressed as a numerical index, calculated from a mathematical function relating the number of different taxa to the distribution of individuals among those taxa. Although not usually reported, the number of samples in which specific taxa appear can also be informative.

The number of different benthic taxa recorded in each sampling period was consistently greater in the reference stream than in the mining-impacted streams, which were quite similar in this respect (Table 15). The number of taxa collected was actually higher in March 1977, following the February freeze, than in the previous sample; however, the number dropped sharply in all streams following the April 1977 flood. This decline in diversity was more acute in the impacted streams than in the reference stream. Other periods of high percipitation prior to the sampling periods in September and October 1976 and August 1977 did not result in marked declines in the number of different taxa taken.

Table 15. The number of different benthic taxa recorded from three southwest Virginia headwater streams between December 1975 and August 1977.

Date	Reference Stream	SMS-1	SMS-2
12/75	42	30	34
3/76	57	34	17
6/76	48	32	37
7/76	48	36	34
8/76	45	31	32
9/76	44	24	21
10/76	40	21	31
11/76	57	24	25
3/77	42	31	34
4/77	30	14	9
5/77	36	20	22
6/77	27	33	16
7/77	28	23	24
8/77	29	27	22

The total number of different taxa recorded over the entire study period was also greater for the reference stream (99 taxa) than for SMS-1 (81 taxa) or SMS-2 (85 taxa). Of the total number of taxa recorded from each stream over the entire study period, only a small percentage occurred in every sampling period. A plot of the cumulative percentage of the number of different taxa occurring in from one to all 14 of the sampling periods (Fig. 8) shows the reference stream to have the shallowest slope, indicating that a greater proportion of the species occurred with greater regularity in the reference stream than in the mining-impacted streams.

Eighty of the 99 taxa found in the reference stream were also noted in at least one of the mining-impacted streams. Nineteen taxa were unique to the reference stream, with 13 of these appearing in at least two collection periods (Table 16). SMS-1 and SMS-2 each had 11 taxa not recorded in the reference stream, with many of these taxa occurring in both impacted streams (Table 16). Only seven of the 11 taxa unique to either of the impacted streams occurred in more than one collection. The study showed that a majority of the benthic taxa were common to all three stream systems. Most of the taxa unique to the mining-impacted streams were uncommon even to those systems, while a majority of the taxa unique to the reference stream were collected more frequently.

Although the overall mean of Brillouin's H diversity index was greater for the reference stream samples than for the mining-impacted streams (Table 17), statistically the difference may be considered marginally significant ($.05<p<.10$).

Fig. 8. Percentage of the total benthic taxa identified in each stream as a function of frequency of occurrence in samples from December 1975 through August 1977.

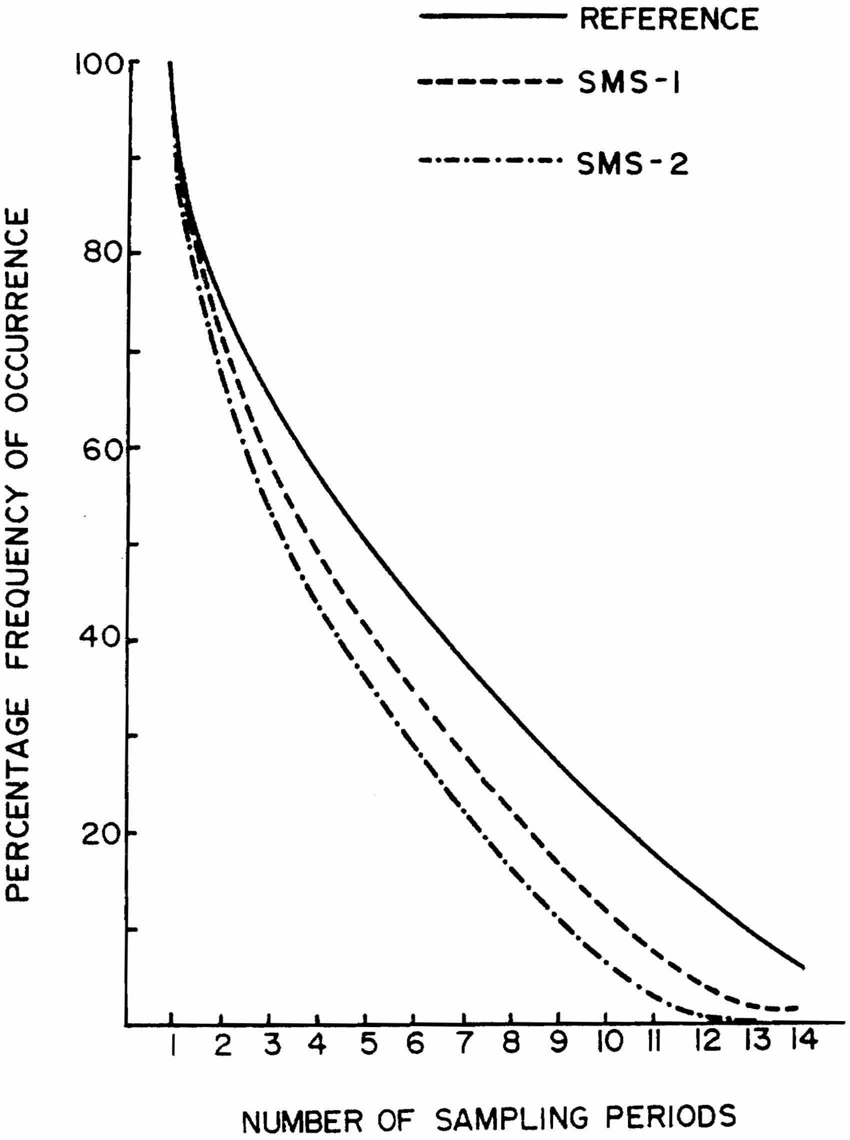

REFERENCE
SMS-1
SMS-2
100
80
60
40
20
PERCENTAGE FREQUENCY OF OCCURRENCE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
NUMBER OF SAMPLING PERIODS

Table 16. Benthic taxa found only in individual streams within the period of common sampling (December 1975 through August 1977). A "1" signifies the taxa unique to SMS-1, a "2" signifies those unique to SMS-2, and no designation implies that a taxon in the mining-impacted streams column was found in both streams. An asterisk indicates the taxa recorded in more than one sampling period.

Taxa unique to the reference stream	Taxa unique to the mining-impacted streams
Orconectes*	Isogenus 1,*
Hydracarina*	Acroneuria xanthenes*
Strophopteryx fasciata	Peltoperla 1
Baetisca carolina*	Baetis*
Heptagenia*	Hetaerina 2
Habrophleboides	Neophylax 1
Isonychia	Wormaldia 2
Lepidostoma*	Agapetus*
Goera*	Rhyacophila 2
Oulimnius latisculus*	Hydrobius
Stenelmis*	Hydrochus 2,*
Ectoparia*	Trichocladius 1
Stichtochironomus*	Limnophila
Chironomid genus A*	Dixa*
Rheotanytarsus*	Chrysops*
Brillia	
Coelotanypus	
Prosimulium	
Sphaerium*	

Table 17. Brillouin's H diversity index for benthic invertebrate collections from three southwest Virginia headwater streams from December 1975 through August 1977.

Date	Reference Stream	SMS-1	SMS-2
12/75	1.172	0.256	0.859
3/76	1.209	1.008	0.745
6/76	1.238	0.882	1.177
7/76	1.135	1.090	1.164
8/76	0.946	1.141	0.649
9/76	0.935	0.996	0.410
10/7	1.124	0.769	0.874
11/76	1.213	0.838	1.082
3/77	1.070	1.118	1.231
4/77	1.146	0.772	0.669
5/77	1.238	0.546	0.788
6/77	0.920	1.000	0.847
7/77	1.043	0.989	0.935
8/77	0.938	1.103	0.749
Mean	1.095	0.893	0.870

Maxima in Brillouin's H index occurred in June and July 1976 and May 1977 for the reference stream, in July and August of 1976 and 1977 as well as March 1977 for SMS-1, and in June and July 1976 and March 1977 for SMS-2 (Table 17). The index was not lower in April, after the February freeze, in the impacted streams but was lower in the reference stream. Following the severe flood of April 1977, the index was reduced by almost 50 percent from the previous month for the impacted stream samples but actually increased in the reference stream. The diversity index paralleled variations in the number of different taxa recorded each sampling period (Table 15) in only a very general way, with sharp increases in the number of taxa associated with an increase in H.

Invertebrate Abundance

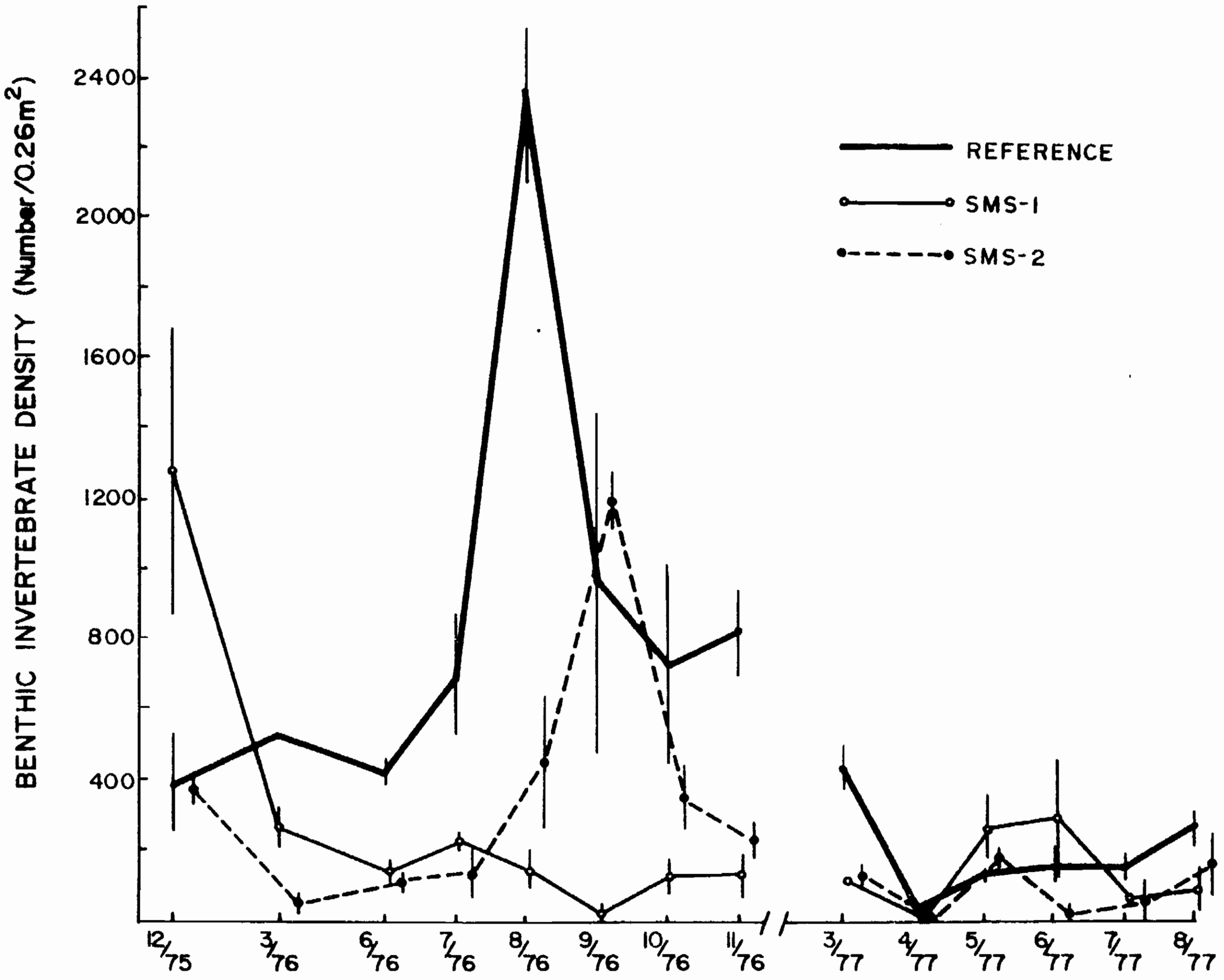
Mean benthic abundance as measured by density estimates (number/ 0.26 m^2) and biomass (g/0.26 m^2, wet weight) was significantly greater ($p<.01$) in the reference stream than in the mining-impacted streams (Table 18 and Appendix Tables III and IV). The impacted streams were not significantly different.

Total benthic density changed little between December 1975 and June 1976 in the reference stream, while density declined in the mining impacted streams (Fig. 9). Benthic density increased sharply in the reference stream through July and August 1976, followed by a fall and winter decline. The benthos of SMS-1 remained at a low level from July through November of 1976, while the density in SMS-2 increased in August and September before falling in October and November. Benthic densities for all streams in March 1977 were still within

Table 18. Mean total benthic invertebrate density (number/0.26 m^2) and biomass (g/0.26 m^2, wet weight) in three southwest Virginia headwater streams from December 1975 through August 1977. Underlined values are not significantly different ($p>.05$).

Parameter	Reference Stream	SMS-1	SMS-2
Mean Total Benthic Density	579.1	235.4	255.4
Mean Total Benthic Biomass	1.398	0.526	0.428

Fig. 9. Total benthic invertebrate density from December 1975 through August 1977 in three southwest Virginia headwater streams. Vertical lines indicate the range in density.


BENTHIC INVERTEBRATE DENSITY (Number/0.26m^2)
2400
2000
1600
1200
800
400
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77
REFERENCE
SMS-1
SMS-2

about 60 percent of the levels in November 1976 despite the freeze in February. April 1977 flooding reduced the benthos markedly in all streams. By May, benthic densities in the impacted streams had "recovered" to levels above those recorded in the reference stream (Fig. 9). However, while benthic density continued a gradual increase in the reference stream through the end of sampling in August, the mining-impacted streams underwent declines to levels below those in the reference stream.

Biomass (g/0.26 m^2, wet weight) increased in the reference stream from December 1975 into mid-summer 1976 (Fig. 10), in spite of the lack of a parallel change in numbers. Biomass declined in autumn but increased slightly over the winter. Benthic biomass in the impacted streams followed the pattern described for density changes, with a consistently low level after an initial drop between December 1975 and March 1976. Winter freezing caused little change in benthic biomass by March, but flooding in April 1977 reduced biomass in all streams. Benthic biomass exhibited a pattern of slow recovery from the April disturbance similar to that described for invertebrate density.

Figure 11 presents the peak two-day cumulative precipitation in the approximately four-week period prior to each sampling date. Rainfall sufficient to cause substantial stream scouring and removal of benthic invertebrates through catastrophic drift, if not actual flooding, occurred several times over the study period. The October 1976 drop in benthic density in the reference stream and SMS-2 may have been due, in part, to the two periods of high rainfall earlier in the

Fig. 10. Total benthic invertebrate biomass from December 1975 through August 1977 in three southwest Virginia headwater streams. Vertical lines indicate the range in biomass.

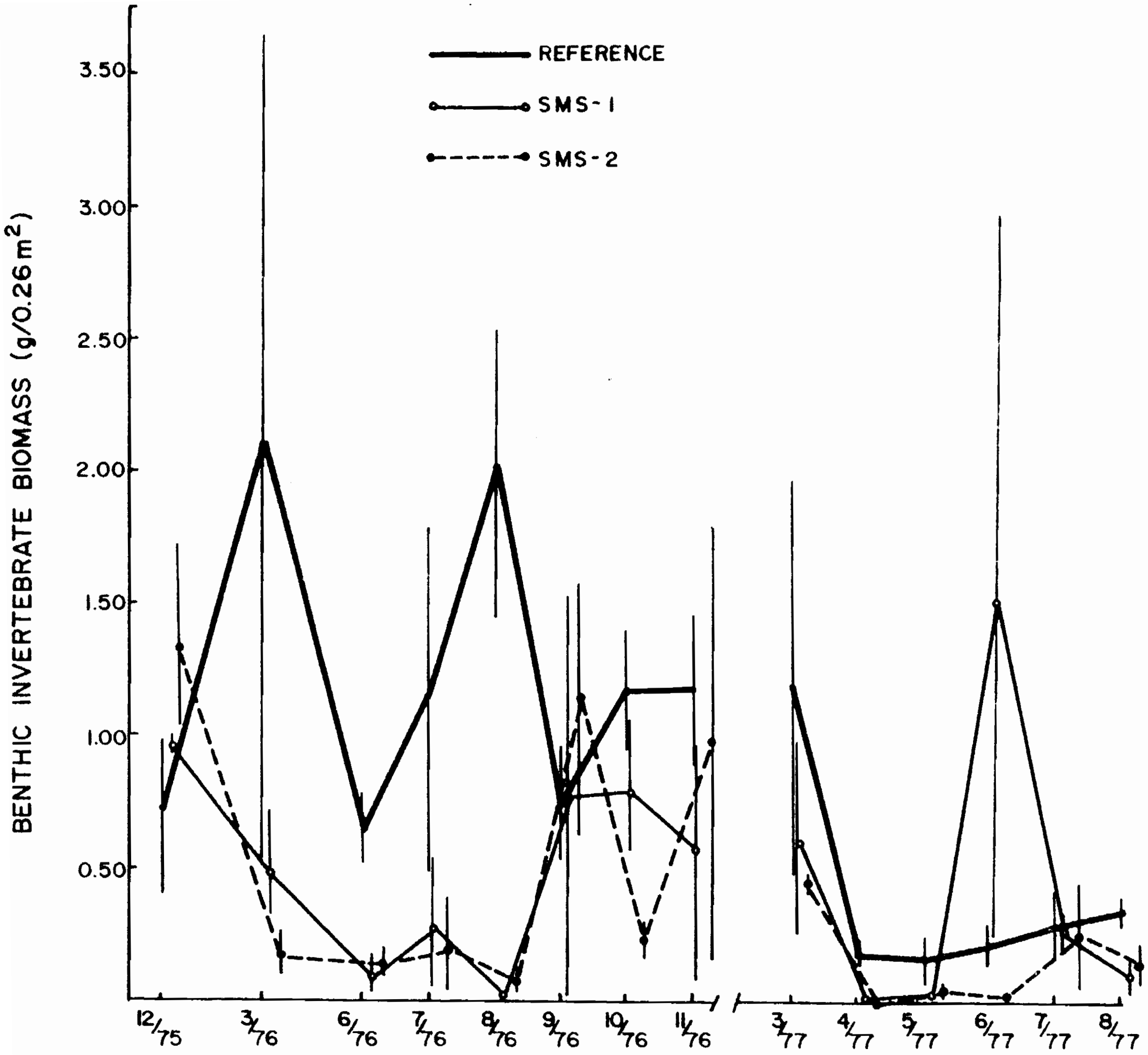
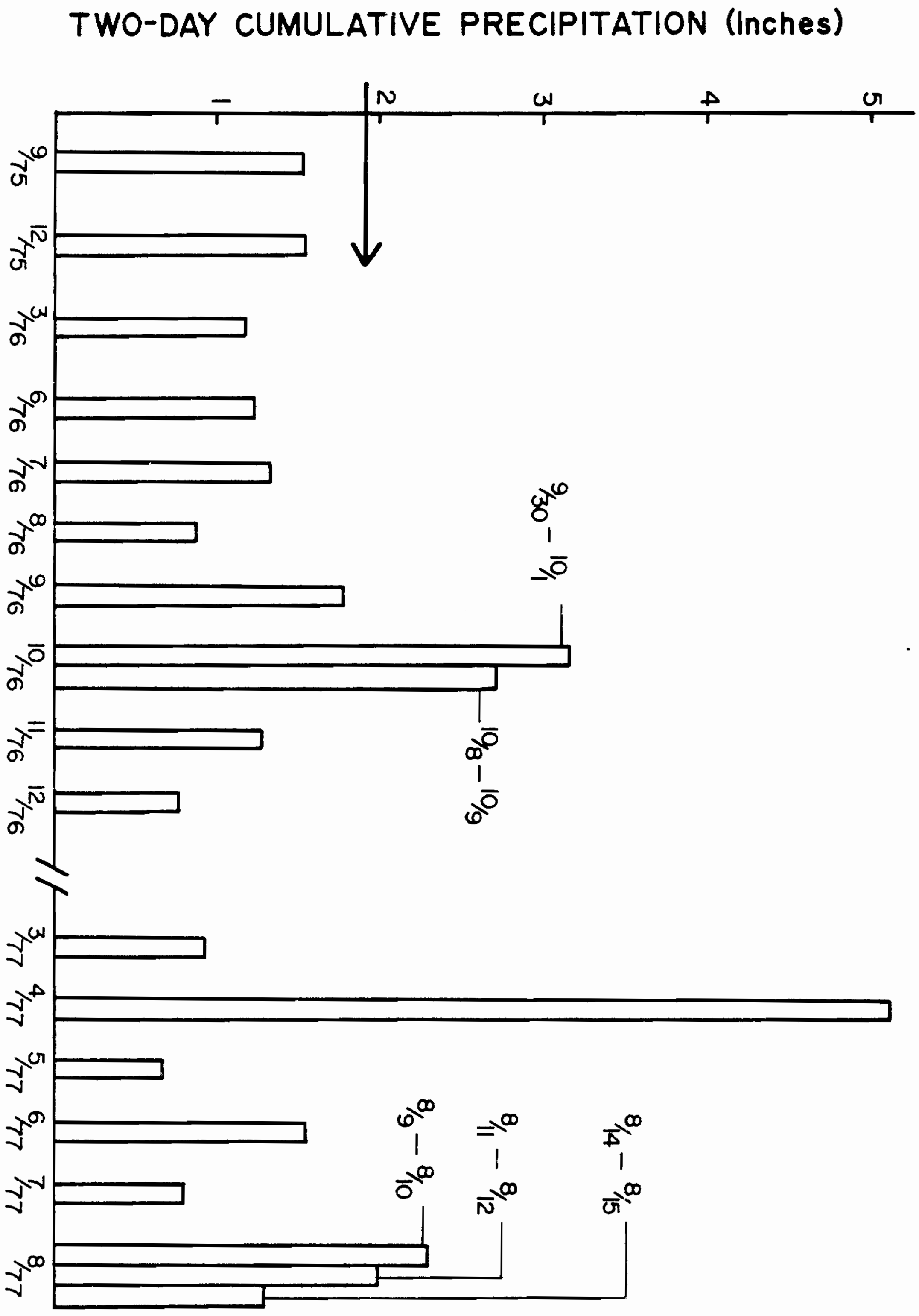

REFERENCE
SMS-1
SMS-2
BENTHIC INVERTEBRATE BIOMASS (g/0.26 m²)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77

Fig. 11. The peak two-day cumulative precipitation in the approximately four-week period prior to each sampling date, as recorded at the John W. Flannagan Lake station. If more than one major peak occurred, all are shown and the date of occurrence recorded. An arrow indicates the minimum recorded two-day rainfall resulting in severe flooding in the area.


TWO-DAY CUMULATIVE PRECIPITATION (Inches)
1
2
3
4
5
9/75
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
12/76
3/77
4/77
5/77
6/77
7/77
8/77
9/30 – 10/1
10/8 – 10/9
8/9 – 8/10
8/11 – 8/12
8/14 – 8/15

month. The unusually large precipitation of early April 1977 also clearly reduced benthic invertebrate density and the elevated peak two-day rainfalls in subsequent months may have contributed to the slow benthic recovery observed in all streams. Conversely, the sharp peak in benthic abundance in the reference stream in August 1976 was preceded by several months of low to moderate total rainfall and low two-day cumulative peak precipitation. No such increase in benthic abundance occurred in the mining-impacted streams over this period.

Trophic Composition

Density estimates and biomass determinations for each of five major trophic groups; collector-gatherers, collector-filterers, predators, shredders, and scrapers (Appendix Table I); were used to calculate the proportion of the total density and biomass represented by each trophic group in each sampling period. Again, crayfish, normally considered collector-gatherers, were not included in the trophic group analysis.

Percentage composition comparisons. The percentage of collector-gatherers based on both density and biomass was significantly less ($p<.01$) in SMS-1 than in SMS-2 and the reference stream, which were not significantly different (Table 19). Collector-filterers were not prevalent in any of the study streams; however, all streams were significantly different ($p<.01$) from each other, with SMS-1 having the largest proportion and the reference stream having the smallest, based on both density and biomass (Table 19). There was no significant difference in the percentage of predators in any of the study streams (Table 19) based on either parameter. Shredders made up significantly

Table 19. Mean percentage of the benthic invertebrates represented by five trophic groups, based on density (number/0.26 m^2) and biomass (g/0.26 m^2, wet weight) in three southwest Virginia headwater streams from December 1975 through August 1977.

	Collector-gatherers		Collector-filterers		Predators		Shredders		Scrapers	
Stream	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
Reference Stream	73.5	42.6	1.7**	1.9**	8.9	13.4	4.1**	14.4**	12.0**	27.8**
SMS-1	53.0**	22.4**	6.4*	10.4**	8.4	15.4	25.8**	48.0**	6.5	3.8*
SMS-2	69.5	47.8	4.1	6.1**	7.4	17.8	11.3**	23.2**	8.0	5.1*

* significantly different among streams, $p<.05$
** significantly different among streams, $p<.01$

different proportions ($p<.01$) of the benthos among all study streams based on density and biomass (Table 19), with the highest values in SMS-1 followed by SMS-2 and the reference stream. There was no significant difference in the percentage of scrapers, based on density, between the mining-impacted streams; however, the proportion was significantly higher ($p<.01$) in the reference stream. All streams had significantly different ($p<.05$) mean scraper biomass, with the highest value in the reference stream and the lowest in SMS-1.

Temporal variations. Collector-gatherers regularly made up a large proportion of the reference stream benthos and this proportion varied little over the seasons (Fig. 12). Although collector-gatherers also represented a major percentage of the benthos in SMS-1 (Fig. 13) and SMS-2 (Fig. 14), broad changes occurred, with the lowest values in late winter to early spring and the highest in summer. Collector-filterers were not sufficiently represented in any of the streams to illustrate a clear seasonal pattern. The representation of predators changed little in any of the streams over the seasons. The maximum percentages of this trophic group occurred in different periods for each stream, but within the period from July through October 1976. Shredders made up a substantial part of the benthos of SMS-1 in almost every sampling period, with marked increases in June, October, and November 1976 and March 1977. The proportion of shredders in the reference stream and SMS-2 were also highest in June, October, and November 1976 and March and April 1977.

Scrapers seldom played a major role in the benthic composition of the impacted streams, but were strongly represented in SMS-2 in

Fig. 12. Percentage of major trophic groups in the reference stream benthos on the basis of density estimates from December 1975 through August 1977.

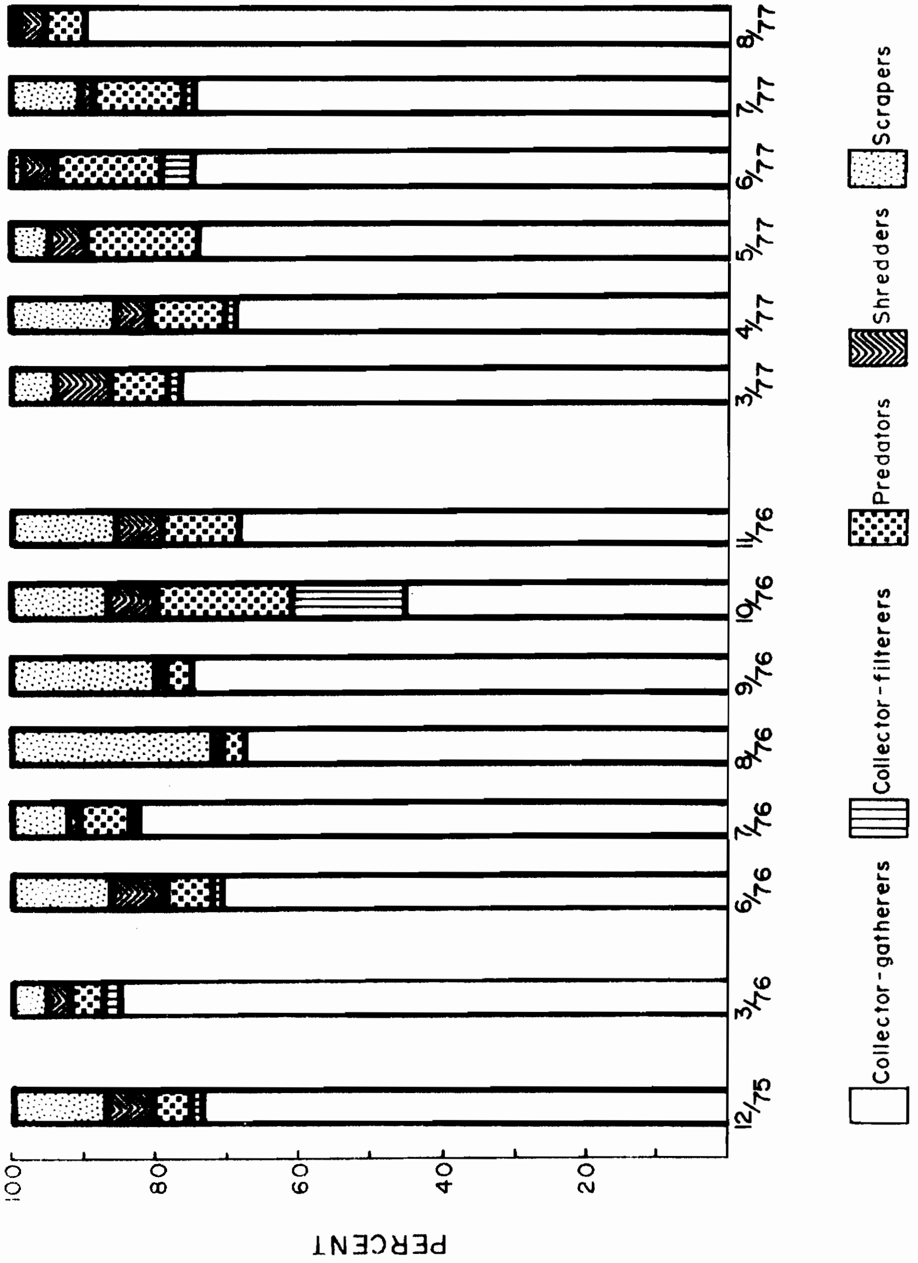

PERCENT
100
80
60
40
20
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77
Collector-gatherers
Collector-filterers
Predators
Shredders
Scrapers

Fig. 13. Percentage of major trophic groups in the SMS-1 benthos on the basis of density estimates from December 1975 through August 1977.

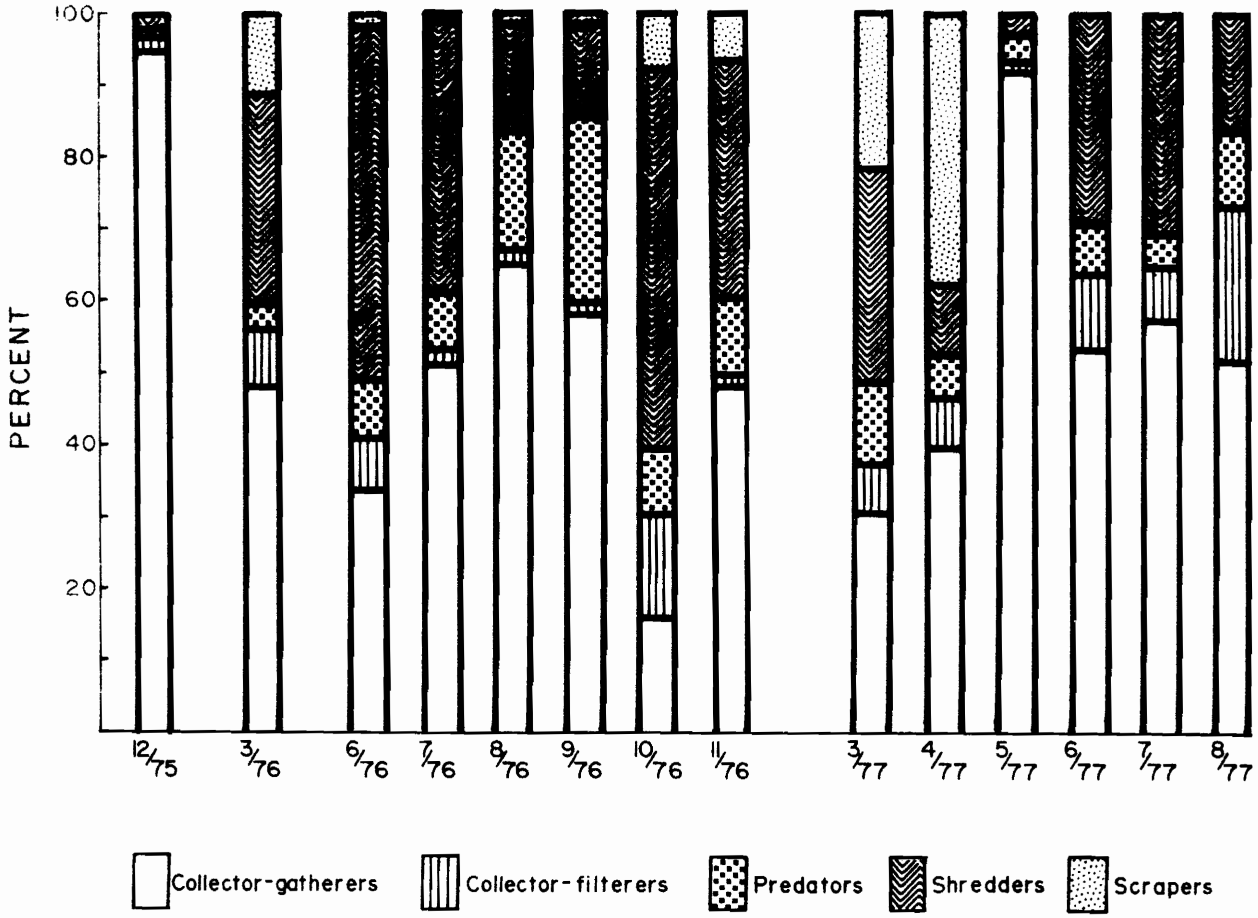
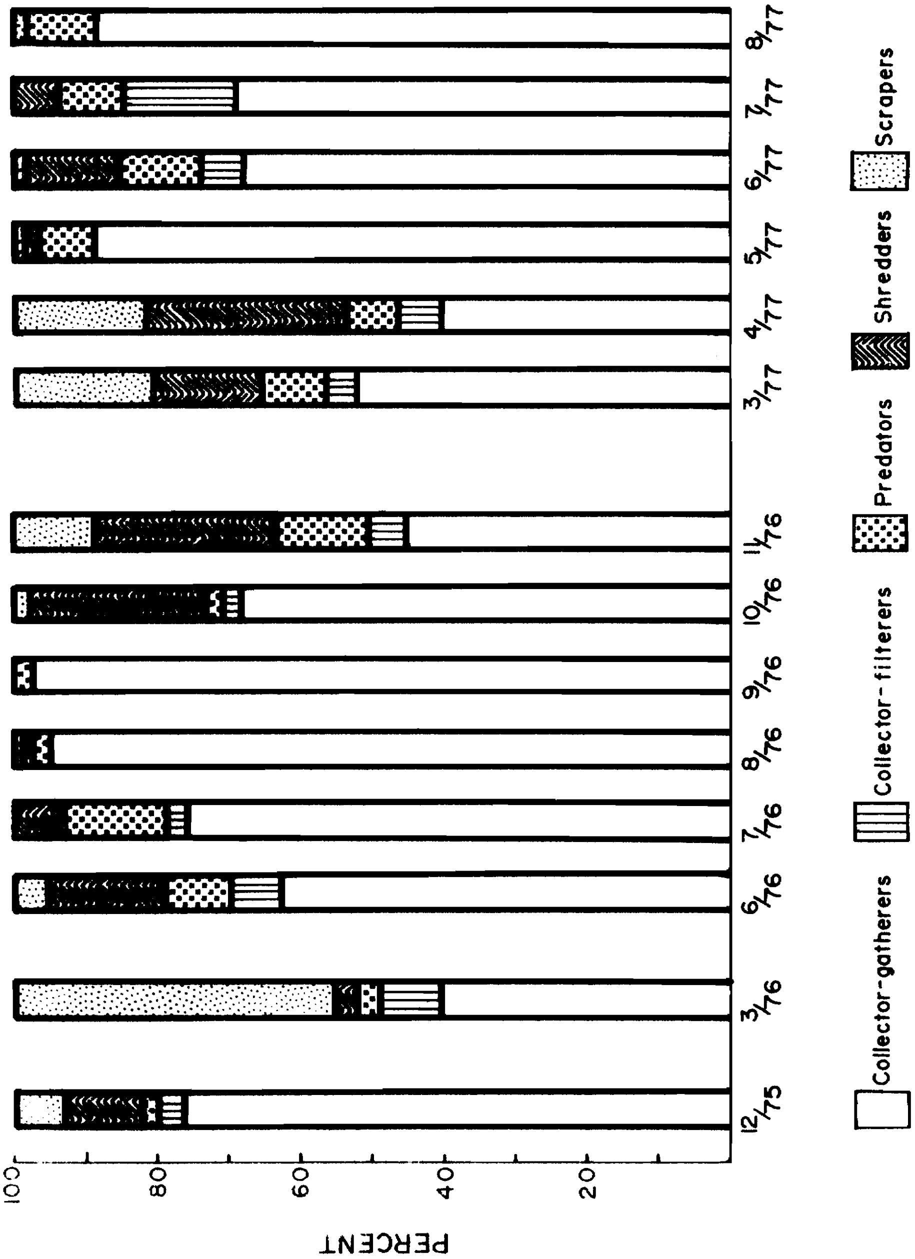

PERCENT
100
80
60
40
20
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77
Collector-gatherers
Collector-filterers
Predators
Shredders
Scrapers

Fig. 14. Percentage of major trophic groups in the SMS-2 benthos on the basis of density estimates from December 1975 through August 1977.


PERCENT
100
80
60
40
20
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77
Collector-gatherers
Collector-filterers
Predators
Shredders
Scrapers

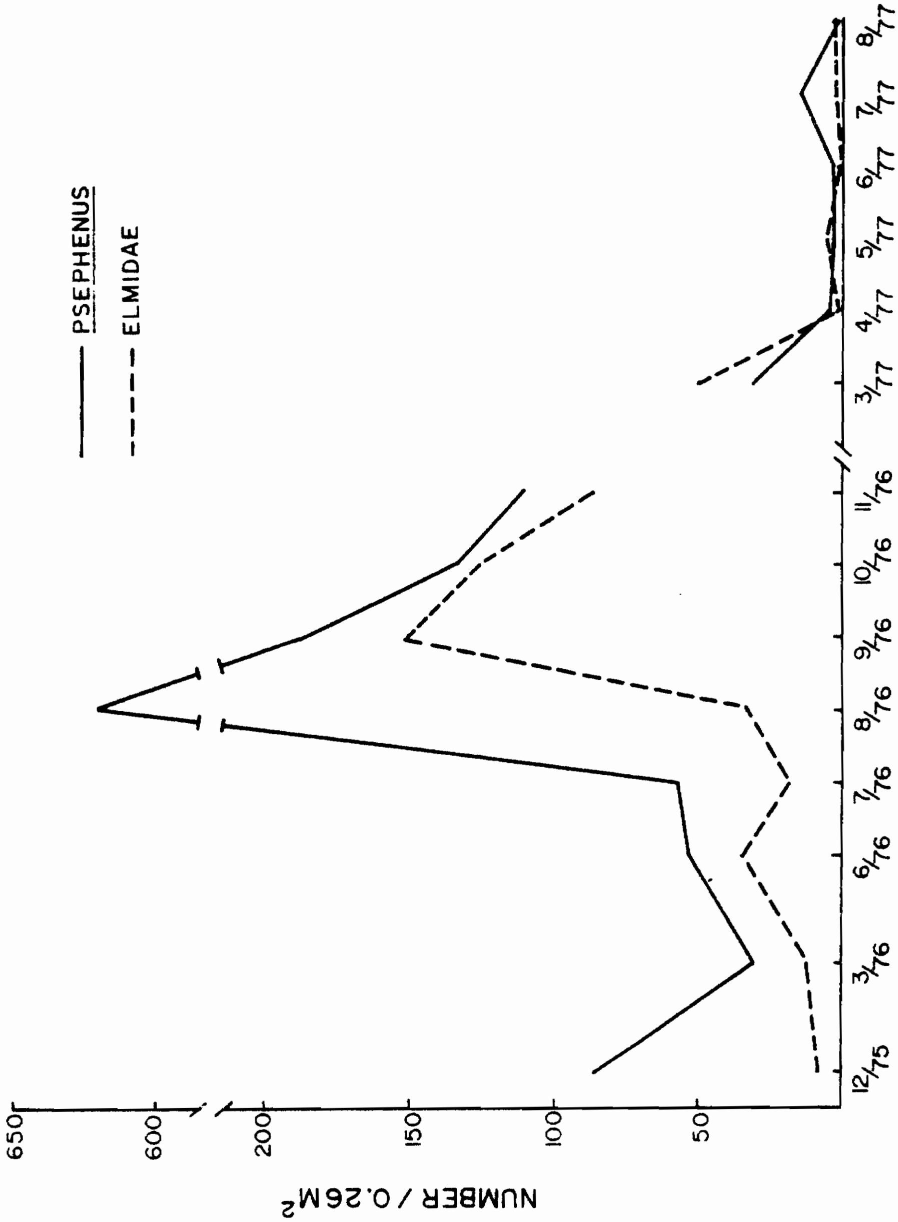
March 1976 and again to a lesser degree in both impacted streams in March and April 1977. Scrapers regularly made up 10 to 15 percent (based on density) of the reference stream benthos, with the highest levels in August and September 1976.

Life History

The benthos of all study streams was predominated by species common to headwater streams and which have univoltine or multivoltine life cycles. Four taxa collected in all three streams have been reported to be capable of inhabiting temporary streams; *Nemoura truncata*, *Allocapnia* (Plecoptera), *Ameletus lineatus* (Ephemeroptera), and *Pseudostenophylax* (Trichoptera).

Only 12 insect taxa collected had life cycles extending beyond one year; *Acroneuria* (Plecoptera), *Cordulegaster*, *Hetaerina* (Odonata), *Sialis*, *Nigronia serricornis* (Megaloptera), Elmidae and the two psephenid beetles, *Ectoparia* and *Psephenus herricki* (Coleoptera). *Acroneuria* were recorded in only three sampling periods at SMS-1 and in four periods at SMS-2, with a maximum of three individuals in a single collection (i.e. an area of 0.26 m^2). A total of 23 *Acroneuria* were collected in eight sampling periods from the reference stream. The odonates, *Cordulegaster* and *Hetaerina*, were represented by a total of five and one individuals respectively over the entire study from all streams combined. Both of the megalopterans were uncommon in all three streams. Elmid beetles were well represented in the reference stream in all sampling periods prior to April 1977 (mean density of 581/0.26 m^2), when high flow reduced their numbers (Fig. 15). Less than 50 elmids were collected from either of the mining-impacted

Fig. 15. Density of *Psephenus herricki* and all Elmidae in the reference stream from December 1975 through August 1977.


PSEPHENUS
ELMIDAE
NUMBER / 0.26M²
650
600
200
150
100
50
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
3/77
4/77
5/77
6/77
7/77
8/77

streams over the entire study period. Of the psephenid beetles, Ectoparia was found only in the reference stream, while Psephenus herricki averaged over 190 individuals per sample prior to April 1977 in the reference stream (Fig. 15). Only three and 29 Psephenus herricki were taken over the entire study in SMS-1 and SMS-2, respectively.

This review of life cycle characteristics shows that few organisms collected had life cycles beyond one year in length. Those few taxa which did have extended aquatic stages were collected infrequently and never in abundance in any of the streams, or were present in abundance in only the reference stream.

Fish

The fish community has been evaluated based on taxonomic composition, abundance and biomass estimates, and seasonal dynamics within each stream.

Taxonomic Composition

Over 95 percent of the fish collected in the reference stream were represented by only three species (in decreasing order of abundance); the creek chub (Semotilus atromaculatus), the stoneroller (Campostoma anomalum), and blacknose dace (Rhinichthys atratulus). These species were encountered in nearly every collection over the study period (Table 20). White sucker (Catostomus commersoni), whitetail shiner (Notropis galacturus),northern hogsucker (Hypentelium nigricans), and the silverjaw minnow (Ericymba buccata) were collected only sporadically (Table 20) and never in abundance in the reference stream.

Table 20. Frequency of collection of fish species from three southwest Virginia headwater streams. The upstream station on each stream is designated as "Up" and the downstream station as "Dn". A total of 16 collections were made from the reference stream and 12 from each of the mining-impacted streams.

Species	Reference Stream		SMS-1		SMS-2	
	Up	Dn	Up	Dn	Up	Dn
Campostoma anomalum	16	14	0	1	0	1
Rhinichthys atratulus	16	16	8	12	2	9
Semotilus atromaculatus	16	15	2	2	2	5
Etheostoma flabellare	0	0	3	7	1	3
Catostomus commersoni	3	3	0	0	0	0
Ericymba buccata	1	0	0	0	0	0
Hypentelium nigricans	1	1	0	0	0	0
Notropis galacturus	1	4	0	0	0	0

A majority of the individuals collected from the mining-impacted streams were blacknose dace (87.4 percent for SMS-1, 84.7 percent for SMS-2), followed by fantail darter (Etheostoma flabellare) in SMS-1 and creek chubs and fantail darter in SMS-2. Stoneroller were taken on only one occasion from each of the mining-impacted streams. No other species were collected from these streams.

Abundance and Biomass

(Total fish abundance (number/50 m^2) and biomass (g/50 m^2) estimates were significantly greater (p<.01) in the reference stream than in the mining-impacted streams,) as well as significantly greater (p<.01) in SMS-1 than SMS-2. The flooding of early April 1977 created a deep pool (maximum depth of over one meter) below a 0.5 m waterfall at the upper end of the downstream sampling station on SMS-2. No fish were collected above this natural barrier in the April 1977 sampling period through the completion of sampling in August, resulting in low mean population estimates for this stream. The high discharge of this same period caused the reference stream to leave its normal channel and flow down a boulder-strewn jeep trail, leaving the upstream sampling station as a dry bed. A 30 m riffle/small pool study section was established within the new channel. The downstream study section in the reference stream was maintained.

The frozen conditions of the mining-impacted streams at the time of the February sampling period almost certainly eliminated any fish from these areas. It is probable that most of the fish were able to move downstream into deeper, more stable pools of Hamlin Branch with the onset of low temperatures.

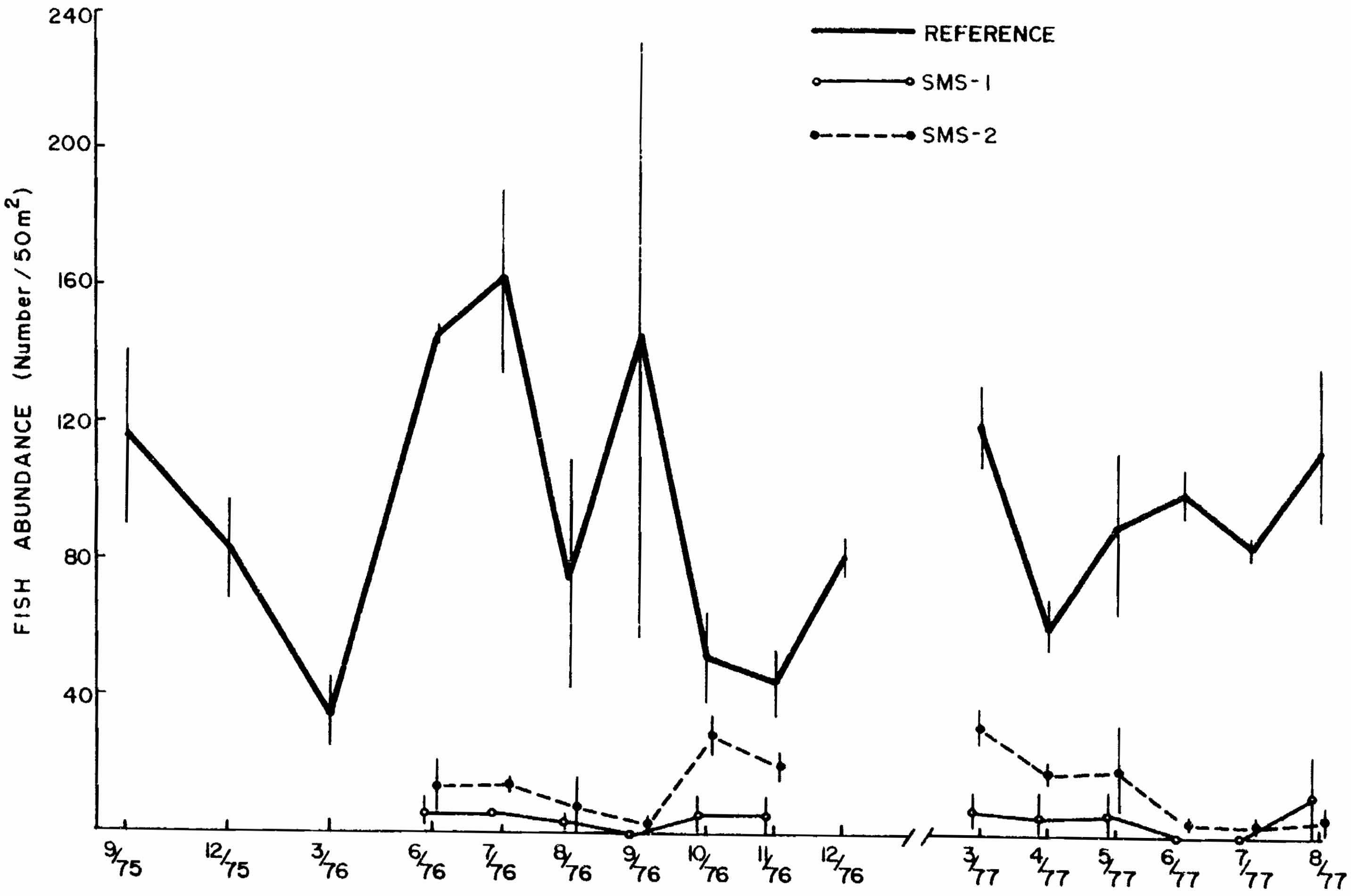
Seasonal Dynamics

Reference stream. Changes in total standing crop estimates of fish can be almost fully described in the reference stream by following the changes in abundance of the three predominant species; creek chubs, stonerollers, and blacknose dace. These species made up over 95 percent of the fish taken.

Abundance estimates for all three major fish species in the reference stream declined from the initiation of sampling in September 1975 through March 1976 (Fig. 16). All three species estimates reached to or near their maxima in June and July 1976, but dropped sharply by August. After a uniform increase in estimates in September, they fell to a fairly low level through October and November 1976. Although stoneroller estimates remained low in December, estimates of creek chub and dace standing crop increased. Following heavy flooding in April 1977, creek chub and dace estimates declined sharply from the moderate levels of the previous month but stoneroller abundance was slightly higher and changed little over the remainder of the study. In the months following the April flood, dace and creek chub standing crop reached pre-flood levels.

White sucker were collected in June 1976 and in June, July and August 1977. Whitetail shiner were encountered in late fall and early winter in 1975 and 1976, while the northern hogsucker appeared only in December 1975. A single silverjaw minnow was taken in June 1977. These infrequently encountered species were never represented by more than three or four individuals per 30 m section and therefore played a small part in the observed changes in number and biomass of fish

Fig. 16. Total fish abundance in three southwest Virginia headwater streams at the time of sampling from September 1975 through August 1977.


240
200
160
120
80
40
FISH ABUNDANCE (Number / 50 m²)
REFERENCE
SMS-1
SMS-2
9/75
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
12/76
3/77
4/77
5/77
6/77
7/77
8/77

in the reference stream. Many young-of-the-year, not included in the population estimates due to differential susceptibility to electrofishing, were observed in the spring and early summer of 1976 and 1977.

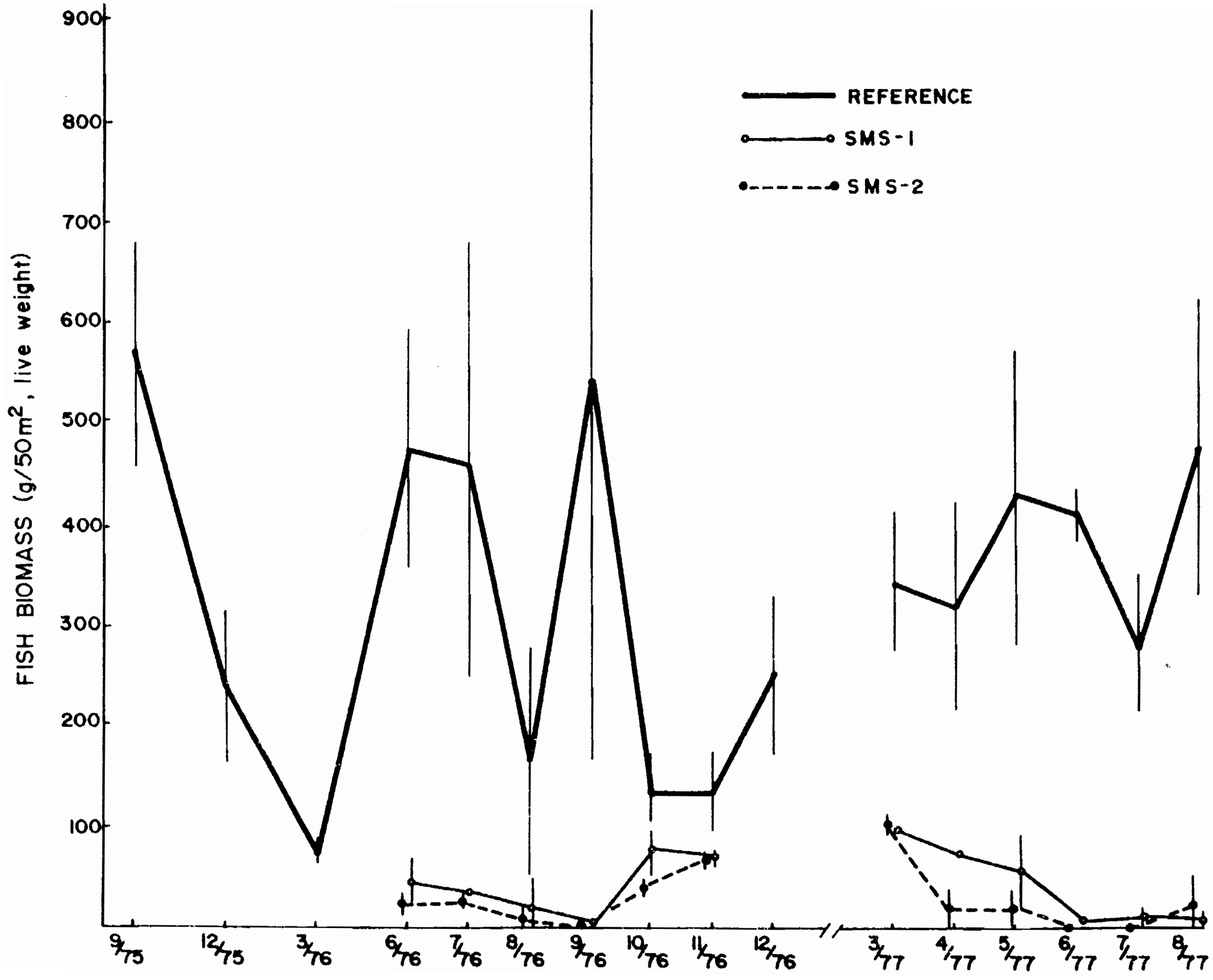
A comparison of total fish abundance, the four-day and four-week rain accumulation prior to sampling, and stream discharge at the time of sampling indicates that population abundance peaks generally correspond to periods of moderate to high water availability. This is especially true when such conditions occurred in spring to early summer, a period often associated with upstream movement of fish for spawning activities. The irregularly encountered species were also taken during periods of moderate water availability and/or in spring to early summer.

Marked declines in abundance estimates were paralleled by low four-day and four-week cumulative precipitation or the onset of low winter temperatures. The number of species collected during these periods was also low.

Changes in total fish biomass (g/50 m^2) closely followed those described for abundance (Fig. 17).

Mining-impacted streams. A majority of the temporal changes in fish standing crop in the mining-impacted streams were the result of variation in the abundance of the single regularly occurring species, blacknose dace. The seasonal changes were strikingly parallel in both streams (Fig. 16), with steady population declines through July, August, and September 1976 from levels in June. The 1976 maxima were recorded in October, followed by a decline into the winter months.

Fig. 17. Total fish biomass in three southwest Virginia headwater streams at the time of sampling from September 1975 through August 1977.


FISH BIOMASS (g/50m², live weight)
900
800
700
600
500
400
300
200
100
9/75
12/75
3/76
6/76
7/76
8/76
9/76
10/76
11/76
12/76
3/77
4/77
5/77
6/77
7/77
8/77
REFERENCE
SMS-1
SMS-2

March 1977 estimates were near the highest observed in the impacted streams throughout the entire study. Abundance declined in April through July, with a sharp increase at SMS-2 in August and a slight rise at SMS-1 for this period.

Fantail darters were found in the impacted streams in June and July as well as in October and November 1976. Darters were also encountered in March and April 1977. Stonerollers were recorded only in August 1977, while creek chubs occurred primarily in October and November 1976 and March and April 1977. Many young of the year, again not included in population estimates, were observed in spring and early summer 1976 and 1977.

The steady decline in abundance and diversity of fish through July, August, and September 1976 was accompanied by a general drop in cumulative rainfall four days and four weeks prior to sampling, as well as a drop in stream discharge. The sharp October/November rise in abundance and diversity occurred at the same time as an increase in four-week cumulative rainfall and stream discharge. The marked physical disruption which occurred with the flooding of early April 1977, although possibly eliminating fish from the upper reaches of SMS-2, seemed to have little effect on estimates from SMS-1 and the downstream area of SMS-2 by the time of sampling in late April.

DISCUSSION

The stream components examined in this study will be singled out for initial discussion. The interactive nature of these components within the stream system will be considered as they impact each other.

Water Quality

Alkalinity, hardness, and sulfate are normally low in Virginia Appalachian mountain streams (Woodall and Wallace 1972; Herricks and Cairns 1974). With the onset of surface mining, measurable alkalinity may be eliminated if acidic materials are exposed during land moving; however, when acid production is not a factor, alkalinity can actually increase if carbonate rock is exposed during mining (Dyer and Curtis 1977; Maughan et al. 1977). Hardness, usually reflecting primarily the concentration of calcium and magnesium ions in natural waters, generally increases with mining as a result of greater calcium and magnesium dissolution as well as the addition of other polyvalent metals (e.g. aluminum, iron, manganese, and zinc) (Dyer and Curtis 1977). Sulfate additions to streams after mining activity originate primarily from the oxidation and dissolution of sulfide minerals, especially iron pyrite (FeS_2). Baker and Wilshire (1970) have shown that oxygen exclusion does not prevent pyrite dissolution and that the oxidation of FeS_2 can proceed solely by chemical means, without the _Ferrobacillus_ and _Thiobacillus_ organisms commonly associated with acid formation from pyrite. Herricks and Cairns (1974) and Minear and Tschantz (1976) have pointed out that sulfate may be one of the most useful indicators of acid mine drainage and mining disturbance since: 1) sulfates are normally low in streams; 2) there is a direct relationship between the molecular weight of sulfate formed and sulfuric acid generated in the disturbed areas; 3) sulfate levels tend to reflect the extent of disturbance and the passage of time since disturbance; and 4) although there may be an initial lag between the initiation of mining and subsequent sulfate generation, sulfate production after the cessation of mining may aid in following long-term "recovery."

Alkalinity, hardness, and sulfate in the study streams followed the pattern outlined above, with low levels of the stated chemicals recorded in the reference stream and elevated levels, generally bearing a direct relationship to the magnitude of the disturbed area, in the mining-impacted streams. That is, the greater percentage of watershed disturbed at SMS-1 was reflected in higher alkalinity, hardness, and sulfate there than in SMS-2.

That sulfate and hardness values varied together in the mining-impacted streams is not surprising since most of the sulfate is carried as dissolved salt complexes with calcium, magnesium, iron, and other available cations. All of these cations also contribute to water hardness, although only calcium and magnesium are accounted for by the EDTA method of analysis.

As in this study, Minear and Tschantz (1976) noted that variation in water quality variables was quite small for natural stream systems in eastern Tennessee and that the natural streams in their study were not significantly different from each other based on selected water quality measures. However, they found that streams in disturbed watersheds underwent extreme oscillations in concentration of specific constituents and that disturbed streams were significantly different among themselves. Disturbed watershed streams appear to be hydrologically heterogenous among themselves and with respect to natural systems. This is largely the result of the exposure of rock, in a highly fragmented condition, to the forces of weathering during and after mining.

The small variation in some chemical constituents in natural streams may make them seem virtually independent of streamflow and antecedent climatological conditions (Minear and Tschantz 1976). This probably does not hold true for disturbed systems. Minear and Tschantz (1976) observed wide oscillations in chemical constituents of disturbed streams, and these changes could not be clearly linked to daily rainfall, as was also the case in this study. Connell et al. (1976) pointed out, however, that in most cases surface runoff is in fact the basic mechanism of chemical transport into streams and that concentration peaks occur at a specific interval following the start of rainfall. This time interval depends largely on the watershed retention characteristics. Only continuous monitoring or sampling stratified so as to bracket concentration peaks would yield data suitable to demonstrate the relationships between precipitation, streamflow, and dissolved chemical concentrations.

Mining disturbance is commonly associated with a drop in pH; however, the mining activities studied have usually included underground shaft mining in combination with surface disturbances. Curtis (1973) found that when considering only surface mining in a part of eastern Kentucky where acid-forming elements are not predominant in exposed rock strata, stream acidity changed very little. Maughan et al. (1977) observed that streams in southwest Virginia draining abandoned surface mines, without shaft mine drainage, seldom had pH values below 6.5. Other investigators have found that exposed carbonate minerals effectively neutralize acids before they enter the stream that the pH consistently increases after mining (Minear and Tschantz 1976; Dyer and Curtis 1977). Although pH was lower in the mining-impacted streams than in the reference stream in this study, it was only slightly depressed and certainly well within levels fully compatible for most aquatic life (Gaufin 1973a).

Since riparian vegetation was little affected by the mining process and organic effluents are uncommon in such operations, water temperature and dissolved oxygen would be expected to exhibit little difference among streams, as was observed. The steep gradient and cobble-boulder substrate maintained dissolved oxygen near saturation in all study streams.

Connell et al. (1976) found that conductance rose in streams after mining disturbance and that conductance values were so strongly correlated with sulfate and calcium that these components could be adequately monitored through continuous recording of conductance. Stream ranking based on conductance paralleled the ranking for sulfate.

Elevated alkalinity, conductivity, hardness, and sulfate values suggest that the water quality of SMS-1 and SMS-2 is still very much under the influence of the disturbed areas within the watershed in spite of reclamation efforts. Noticeable "recovery," as measured by the selected water chemistry parameters, did not occur over the study period. When water chemistry measures from the mining-impacted streams are compared to those determined for other headwater streams in the area under the influence of abandoned surface mines, the study streams reflected a water quality status comparable to a ten-year post-abandonment stream. The observation by Dyer and Curtis (1977) that recovery in water chemistry parameters in streams draining mining-impacted watersheds is very slow, with little improvement even 4.5 to 5.5 years after mining, holds true for the mining-impacted streams in this study.

Particulate Matter

Benthic Materials

Benthic fine-particle inorganic material (FPIM). Sediment includes organic as well as inorganic particles (Hesser et al. 1975). Inorganic sediment is a detrimental by-product of nearly all major land disturbances, which may impact not only the immediate stream area, but which also may be felt far downstream.

Sediment associated with surface mining originates from the area of land disturbed during coal extraction and, perhaps more importantly, from the construction, use, and abandonment of haul roads (Weigle 1966; Plass 1967; Hill 1971). Haul roads continued to carry vehicular traffic after reclamation and supported little vegetation in the areas adjacent to the mining-impacted streams. These bare areas were probably major contributors to stream sediment loading. Hesser et al. (1975) noted that increased turbidity and sedimentation in streams following forest clearcutting in the watershed could be attributed almost exclusively to the construction and use of haul roads and skid trails, and that the problem would continue long after disturbance had ended if such access points were not permanently closed to travel and revegetated. Reclamation must be complete since disturbance of only a very small percentage of a watershed may still result in substantial erosion and sedimentation (Curtis 1973).

Turbidity and suspended solids have commonly been used to quantify the magnitude of sedimentation. Minear and Tschantz (1976) found turbidity to be an unreliable index of suspended solids in streams, and Gammon (1970) found that sediment which settled out in riffles caused a 40 percent decrease in benthic invertebrate populations regardless of the suspended solids concentration. Curtis (1973) and Minear and Tschantz (1976) followed the accumulation of sediment behind gaging weirs, but such data may have little relevance to the stream bed conditions to which upstream biotic populations are subjected. Gammon (1970) was able to estimate the daily rate of sediment accumulation below a crushed rock quarry based on a longitudinal series of suspended solids estimates and data on stream discharge; however, he concluded that the most simple and reliable method of determining settling rates was direct observation. Reductions in benthic populations were observed even in the absence of visible accumulation of sediment. Hill (1971) abandoned all proposed techniques for collection and characterization of stream bed materials because they were inappropriate for delineating differences in the fine particle fraction in streams dominated by large rocks and boulders.

Curtis (1973) warned that interval sampling may not represent actual maximum sediment concentrations. The procedure employed in this study was easily repeated in each sampling period for each stream and was sufficiently precise to consistently detect significant differences in benthic sediment between the reference stream and the mining-impacted streams, demonstrating that broad changes in sedimentation occur in mining-impacted streams over time.

Maughan et al. (1977) observed that immobilization of fine particles at their source permitted streams to naturally flush. No such recovery was observed in this study, due primarily to continual FPIM inputs despite the reclamation efforts in the disturbed area.

The effects of suspended solids and inorganic sediments on aquatic biota have been effectively reviewed by Cordone and Kelley (1961), Gammon (1970), and Sorenson et al. (1977) and will not be treated here. Effects specific to the findings of this study will be discussed in conjunction with the biotic population data.

<u>Benthic fine-particle organic material (FPOM)</u>. Mishall (1967), Hynes (1970), and Lynch et al. (1977) noted that FPOM can become mixed with, deposited with, and covered over by inorganic sediment. It is natural for a certain proportion of stream bed sediment to be organic and for successively deeper layers of fine deposits to also contain organic constituents. This explains why benthic FPOM density (g/cm^2) was greater in the impacted streams than in the reference stream and why the reverse was true for the percentage of organic material in fine deposits. Since the mining-impacted streams had much thicker sediment deposits, more organic material was trapped in a given unit area

of stream bed than in the reference stream, which had only a very thin fine-sediment layer. However, because of the abundance of inorganic particles in the impacted streams, the organic fraction made up a significantly smaller proportion of the total sediment. Although FPOM density was higher in the mining-impacted streams, the availability of this material to invertebrate collectors was limited in two ways. FPOM held within sediment deposits was not readily accessible to non-burrowing forms and secondly, the preponderance of inorganic material of the same size range as the nutritive organic particles would require more energy for selective ingestion or, more likely, more energy for simply increased ingestion, digestion, and egestion by collectors than would be required if a larger proportion of the fine sediment were organic, as in the reference stream.

The suspended fraction of FPOM has often been assessed in accounting for inputs and outputs in lotic systems, but the contribution and dynamics of benthic FPOM has largely been ignored. Benthic FPOM made up 60, 84, and 83 percent of the estimated particulate organic matter standing crop in the reference stream, SMS-1, and SMS-2, respectively. Benthic FPOM standing crop generally increased after increases in benthic LPOM were observed, but was sharply reduced by flooding as was LPOM. Benthic FPOM represented a significant component of the organic material reservoir in the study streams.

Benthic large-particle organic material (LPOM). The intimate relationship between LPOM and its microbial coat generally renders the separation of the two detrital components impractical. The impact of surface mining on aquatic microorganisms and their role in allochthonous material processing is virtually unknown. The degree and composition of microbial colonization of LPOM among streams was not evaluated in this study; however, the observed differences in water quality should affect the rate and the type of microbial colonization.

LPOM inputs generally peak in autumn and, to a lesser degree, in spring (Woodall and Wallace 1972; Fisher and Likens 1973; Webster 1975). Leaves form a clumped distribution pattern within streams, often occurring as accumulations called leaf dams or leaf packs, which are in a continual process of transport and redeposition (Egglishaw 1964; Fisher and Likens 1973; Boling et al. 1975). The impact on stream energy budgets resulting from removal of organic material by storm flows has not been investigated.

Benthic LPOM standing crop peaked in autumn in all study streams; however, a second peak in July occurred in both years in only the reference stream. LPOM densities apparently remained stable over the winter months despite ice accumulation. Flooding sharply reduced benthic LPOM and recovery was slow, especially in the mining-impacted streams. Virtually all leaf packs had been flushed from the study sections.

Benthic LPOM standing crop was significantly greater in the reference stream than in the mining-impacted streams, probably as a result of the smoother substrate leading to greater transport of LPOM out of the latter systems. Abundant sediment deposition reduced the overall "coarseness" of the substrate.

Substantial amounts of LPOM were collected from below the surface of the substrate, suggesting that a subsurface organic material reservoir exists which can gradually release energy to the stream system over time. Low LPOM standing crop in the months after April flooding indicated that the subsurface reservoir had been depleted and was not immediately recharged.

Webster (1975) found a larger percentage of leaf material greater than 0.7 mm diameter being transported out of stream reaches in disturbed watersheds than out of a natural-state hardwood forest watershed. This suggests that there is greater retention and detrital processing efficiency in the more "mature" forest stream. Correspondingly, a larger proportion of the benthic particulate organic matter reservoir should also be in larger size-fractions in disturbed streams as a result of decreased processing capabilities.

No significant difference in the proportion of benthic LPOM greater or less than five centimeters in diameter was found among streams. However, this size distinction may not have been adequate to delineate the hypothesized size distribution. Considering total benthic particulate organic material (i.e. benthic FPOM and LPOM), the fraction which was LPOM was less in the mining-impacted streams than in the reference stream, apparently contrary to expectations from Webster's hypothesis. However, the greater representation of benthic FPOM and lower proportion of LPOM in the mining-impacted streams was primarily the product of two abiotic conditions: first, the abundant inorganic sediment trapped substantial amounts of FPOM within the substrate and second, transport characteristics of the impacted streams as a result of sediment deposition tended to reduce benthic LPOM.

Suspended Materials

Suspended fine-particle material (FPM). The greatest part of the suspended fine-particle load was probably represented by inorganic sediment in transport. Inorganic particles carried into the stream from disturbed areas on the mined land and particles swept from the benthic load contributed to the elevated levels in the impacted streams. Suspended fine particles increased following flooding, primarily as the result of sediment additions from the mined area and from newly eroded stream banks. Suspended FPM reduces the depth of photosynthetically effective light penetration, acts as an abrasive agent, and enters the benthic load with settling in downstream areas.

FPOM makes up an ecologically significant part of the suspended particle load (Cummins 1974; De la Cruz and Post 1977) and is dominated by terrestrially derived detritus as opposed to diatomaceous material, usually the only other significant organic contribution (Egglishaw and Shackley 1971; Karlstrom and Backlund 1977). Due to the abundance of fine-particle inorganic material in the impacted streams, suspended fine-particle organic material probably represented a much smaller proportion of the total suspended solids than in the reference stream. Therefore, suspended fine-particle organic material would not be as readily available to size-selective filter-feeding invertebrates in SMS-1 and SMS-2 as in the reference stream.

Suspended large-particle organic material (LPOM). During high flow periods, the transport of organic matter is greatly increased, being disproportionately higher than the increase in discharge (Egglishaw and Shackley 1971; Fisher and Likens 1973). Although much of the transported material may be swept from the bank and rapidly carried through the system, playing a minimal role in the annual energy budget (Cummins 1974), LPOM transport in general must be characterized as pulsed, with dislodgement of leaf accumulations resulting in peak loads (Fisher and Likens 1973). Short-period sampling at regularly spaced intervals, as conducted in this study, will generally underestimate flux rates but will yield adequate comparative data. The configuration of the stream bed, especially with regard to the depth and expanse of pools and the presence of interstitial spaces, undoubtedly influences LPOM retention and transport (Hynes 1975). The stability of leaf accumulations within the stream can influence their rate of processing.

Suspended LPOM density was highest in all study streams during periods of increased flow and/or during autumnal leaf-fall. The transport of LPOM out of the impacted streams was significantly greater than transport out of the reference stream. The ubiquitous inorganic sediment of the mining-impacted streams, filling pools and interstices and generally "leveling out" the substrate, probably resulted in greater transport and less retention of LPOM as compared to the reference stream.

No significant difference in the proportion of suspended LPOM greater than or less than 5 cm in diameter was found among streams. Considering total suspended particulate matter (i.e. suspended FPM and LPOM), the fraction which was LPOM was greater in the mining-impacted streams, as predicted by Webster's hypothesis.

Aufwuchs

Instream primary production (i.e. autochthonous input) depends on the presence of vascular macrophytes, algae, and chemosynthetic microorganisms. The status of chemosynthetic production in streams is not well described. In mountain streams, substantial stream bed coverage by higher aquatic plants is rare, and plant community production seldom exceeds respiratory costs (Hynes 1970; Fisher and Likens 1973). The magnitude of the contribution by attached algae varies with the availability of light, suitable substrate, dissolved nutrients, water temperature regime, and stream flow characteristics; however, in few situations is the organic assimilation by algae sufficient to make up a significant proportion of the stream energy budget (Hynes 1970; Hall 1972).

In collecting material from rock surfaces by areal scrapings and from interstitial spaces by the suction removal technique in the present study, it was assumed that algal Aufwuchs would exert its major contribution on rock surfaces due to the habitat stability and exposure to stream currents (Hynes 1970), while terrestrial FPOM would dominate in the low flow areas around interstices. The silt layer covering rock surfaces as well as interstitial spaces in the mining-impacted streams completely confounded any differences between the habitats. Although a relatively diverse algal community occurred on rock surfaces in the reference stream, algal cells never predominated over amorphous detritus on either the rock surfaces or in interstices. Therefore, quantitative comparisons (i.e. ash-free dry weight/unit area) of algal Aufwuchs were not feasible and analysis was limited to taxonomic observations.

The restricted diatom flora of the mining-impacted streams was probably the product of the shifting, fine-particle substrate. Curtis (1973) reported that storm flows increased in streams draining surface-mined areas and Lynch et al. (1977), considering clearcutting as a forestry practice, reported that disturbed areas experienced not only increased peak storm discharge, but also a decrease in the time to the incidence of peak discharge and a longer period of storm flow recession. Cummins (1974 citing a personal communication with R. L. Vannote) explained that spates may prevent the establishment of a filamentous algal system in streams. Storm flows were not recorded in this study; however, it is probable that the mining-impacted streams were subject to increased storm flows which contributed to adverse conditions for algal growth. Even in the absence of increased storm flows, the mining-impacted streams would exhibit greater benthic scour than the reference stream due to the large fine-particle sediment load. Patrick (1978) found that the diatom community undergoes significant changes in the presence of trace metals, the concentrations of which are often increased in streams after surface mining has been initiated in the watershed (Curtis 1973; Minear and Tschantz 1976; Dyer and Curtis 1977). The significance of surface mining impacts on algal communities in streams and the resulting ecological ramifications are areas requiring further investigation.

Benthic Invertebrates

Studies of benthic invertebrates in perturbed ecosystems have utilized both the indicator organism and the community level approach. Indicator organisms which may be considered diagnostic with respect to habitat quality and the occurrence of specific pollutants often cannot be found. Gaufin (1973b) has suggested that the composition and diversity of animal and plant communities are more reliable measures of water quality since they represent the summation of antecedent conditions. The community level approach, treating taxonomic composition and diversity, abundance, trophic composition, and life history, was employed in the analysis of invertebrate populations in the present study.

Taxonomic Composition

Aquatic insects, especially Ephemeroptera, Diptera, Plecoptera, and Coleoptera, predominated in the study streams. The largest non-insect group was Oligochaeta.

Analysis of the taxonomic composition of benthic invertebrates included density estimates for major taxonomic groups, the percentage of total benthic density represented by major groups, and benthic community diversity.

Percentage and density comparisons. The densities of Ephemeroptera, Coleoptera, and Oligochaeta were consistently higher in the reference stream than in the impacted streams, while the densities of Plecoptera and Diptera were consistently greater in SMS-1 than in the other two streams. Trichopteran densities, low in all study streams, were not significantly different among streams.

The percentage of total benthic density represented by Ephemeroptera, Coleoptera, and Oligochaeta were consistently higher in the reference stream than in the impacted streams, and the percentage of Ephemeroptera was significantly different between the impacted streams. Plecoptera and Trichoptera made up significantly greater proportions of the benthos in the impacted streams than in the reference stream and the impacted streams differed between themselves. The percentage of Diptera was significantly greater in SMS-1 than in the other streams.

Differences in substrate among streams, known to be an important factor in the distribution of benthic invertebrates (Mackay and Kalff 1969; Hynes 1970; Barber and Kevern 1973), were probably the major cause of the differences in major taxonomic group density and percentage composition in the study streams. Fine sediment, an unstable, shifting substrate which can reduce food availability to benthic invertebrates, is particularly unsuitable for the taxa which were observed to be less abundant in the impacted streams. Diptera are one of the few groups containing members which can flourish in fine-particle substrates (Mackay and Kalff 1969) and which can be an important component of disturbed watershed streams (Woodall and Wallace 1972). The strong representation of Plecoptera in the impacted streams may be explained by the strong association of stoneflies with LPOM, especially leaf packs, in the substrate (Egglishaw 1964; Mackay and Kalff 1969; Woodall and Wallace 1972). Leaf packs provided relatively silt-free substrates for plecopteran habitation as well as a food source in the impacted streams, especially in SMS-1 where these factors may have been limiting for many invertebrates due to the stream's disturbed condition, based on water quality parameters and sediment deposits. Despite the fact that benthic LPOM density was greater in the reference stream than in SMS-1, Plecoptera were more prevalent in the latter. This apparent contradiction may result from interspecific competition. Mackay and Kalff (1969) found leaf packs to provide the greatest habitat diversity of all other stream bed materials studied, and leaves supported the highest number of species and the second highest density of invertebrates. Thus, plecopterans in the reference stream may have been subject to competitive pressures from the many other invertebrates having leaves and detritus as preferred habitats, while plecopterans in the impacted streams were more free to exploit the available leaf pack habitat.

Gammon (1970) observed a consistent reduction across all benthic taxa as a result of fine-particle sediment additions, while Rosenberg and Wiens (1975) observed differential entry into the drift following experimental sediment additions. Results from this study suggest that benthic invertebrates respond differentially to long-term, chronic sediment additions.

Temporal variation. Temporal variations of major invertebrate groups were within the general pattern described by Hynes (1970). Ephemeroptera were most prevalent in the summer in all streams; however, the major contribution was made by only one or two taxa which differed between years in SMS-1, while the other streams exhibited similar successive periods of abundance and decline for several ephemeropterans over the summer. This suggests that the mayflies present in

SMS-1 may be largely the product of continual but haphazard recolonization from the mainstream, while the other streams support relatively stable resident populations.

Plecoptera in all streams exhibited a bimodal pattern, with abundance peaks in spring and late autumn/winter. Abundance peaks of Plecoptera, many of which are large-particle shredders, have been linked to the timing of maximum LPOM inputs (Woodall and Wallace 1972; Hynes 1970; Boling et al. 1975; Webster 1975). The taxonomic composition differed between seasonal peaks but was similar each year within peak periods.

There was no clear seasonal pattern for Diptera in any of the streams. Coleoptera, strongly represented only in the reference stream, also had no apparent seasonal pattern.

The frozen stream conditions in February 1977 did not produce a sharp drop in invertebrate density or a marked change in invertebrate composition. Hynes (1970) stated that the significance of ice formation to invertebrate mortality is little understood.

Flooding in April 1977 severely reduced all benthic taxa in all streams; however, the pattern of recovery was different in each stream. Coleoptera were most dramatically impacted in the reference stream and were very slow to recover. Plecoptera were nearly eliminated. Ephemeroptera and, to a lesser extent, Diptera made up the greatest proportion of the post-flood benthos. In SMS-1 the normally abundant plecopteran fauna was sharply depressed and Diptera predominated in the post-flood benthos. Although Ephemeroptera and Plecoptera were almost eliminated in SMS-2, plecopteran numbers remained very low while ephemeropterans underwent relatively rapid recovery. The post-flood benthos was a balance between Ephemeroptera and Diptera.

Anderson and Lehmkuhl (1968) observed marked increases in invertebrate drift rate associated with water level increases resulting from as little as 0.30 cm of rain. Benthic reductions in April 1977 in this study were certainly attributable to substantial flood-induced catastrophic drift. Hoopes (1975) recorded major declines in benthic diversity and abundance in a central Pennsylvania headwater stream following the flooding associated with Hurricane Agnes in June 1972. Siegfried and Knight (1977) noted even more severe reductions in diversity and abundance with repeated "washouts" in a Sierra foothills stream. Both studies showed benthic recovery to be slow since such a large part of the substrate had been disturbed that only natural reproduction and subsequent recruitment could make major contributions to recolonization as opposed to downstream drift from unaffected upstream areas, vertical recolonization out of the deep hyporheic substrate or upstream migration (Williams and Hynes 1977). Plecoptera suffered the greatest reductions, while baetid mayflies and some Diptera were least affected. The recovery fauna described in both flood-impact studies was composed largely of Diptera and Ephemeroptera.

The slow post-flood recovery of Coleoptera in this study was probably compounded by their relatively long life cycle, as discussed more fully in the treatment of life history data. Plecopteran recovery may have been impacted by the severe loss of LPOM on which they depend for both living space and food supply. Diptera and Ephemeroptera, having the shortest life cycles of the major taxa, dominated the post-flood fauna. The recovery of all taxa may have been hindered by the occurrence of additional high rain and runoff in the months after the April flood.

It has been suggested that recurrent periods of high flow causing the loss of detrital particles, Aufwuchs, and benthic invertebrates may act as a limiting factor for benthic production, diversity, and standing crop (Tebo 1955; Anderson and Lehmkuhl 1968; Hynes 1970; Siegfried and Knight 1977). Observations in this study indicated that precipitation, sufficient to cause substantial stream scouring, was a common occurrence. Such natural disturbances may have acted as a limiting factor to benthic development as well as to recovery from catastrophic phenomena in all streams. Mining disturbance facilitates scouring through higher rates of storm flow and sediment-mediated abrasion.

Diversity. It has been widely argued that taxonomic diversity leads to or indicates community stability, perhaps as a result of functional redundancy. However, evidence for this hypothesis is not totally convincing and there are some profound theoretical weaknesses (Goodman 1975; Ehrenfeld 1976; Porter 1977). Information theory-based diversity indices (e.g., Brillouin's H index), having both a species richness and eveness component, are a measure of the uncertainty associated with the specific identity of any given organism selected at random (Pielou 1966). Goodman (1975) however, contends that none of the commonly used diversity indices reflect any biological mechanism and defy reasonable interpretation. In an effort to avoid the trappings of the diversity-stability hypothesis, I have relied on measures of taxonomic diversity only in a comparative context. Empirical evidence in other studies indicates that environmental stressors resulting from mining disturbance lead to a reduction in benthic diversity and amelioration of these impacts leads to recovery marked by increased diversity (Cairns et al. 1971; Simmons 1972; Nichols and Bulow 1973; Dills and Rogers 1974; Herricks and Cairns 1974).

Taxonomic richness, based on both the number of different taxa recorded from each stream in each sampling period and on the total number of different taxa recorded from each stream over the entire study, was greater in the reference stream than in the impacted streams. A larger share of the taxa recorded in the reference stream occurred with greater regularity than in the impacted streams, while many of the taxa unique to the impacted streams were single occurrences, suggesting that the impacted stream fauna may be strongly influenced by "recolonizers" or pioneer species from the second-order receiving stream. These taxa may play a variable role in the dynamics of the headwaters depending on the ability of these streams to meet the habitat requirements of the invaders. In contrast, many of the taxa unique to the reference stream were collected regularly and may, therefore, reflect a diversity of stable habitat not found in the impacted streams. It has been demonstrated that the number of species increases as habitat diversity and stability increase (Mackay and Kalff 1969; Hynes 1970).

The mean of Brillouin's H diversity index was greater for the reference stream samples than for the mining-impacted streams, although the difference was marginally significant. Goodman (1975) warns, however, that if numerical diversity indices are not obviously definitive, statistical analyses of such indices are even more removed from ecological significance. Taxonomic and numerical data clearly indicated that the number of benthic taxa and benthic abundance were lower in the impacted streams and that the distribution of individuals within major taxa was significantly different among streams. Brillouin's H diversity index was not particularly sensitive to these differences.

Brillouin's H diversity index paralleled variation in the number of different taxa recorded each sampling period in only a very general manner. Maxima in the diversity index occurred during mid-summer and spring in all streams. Peak numbers of taxa were recorded during early spring and summer for all streams and in winter for the reference stream.

Brillouin's diversity index did not respond similarly among streams to the disturbance of flooding. While the index fell sharply in the impacted streams, it actually increased in the reference stream despite drastic declines in the number of taxa collected and in total abundance. The few individuals collected were sufficiently dispersed across the taxa to result in a high measure of eveness diversity. Within two to three months after the flood, the diversity indices in the impacted streams returned to pre-flood levels, despite observed differences in taxonomic composition from pre-flood conditions. Hoopes

(1974) observed significant declines in the mean number of benthic taxa, mean number of individuals, mean sample displacement, and mean benthic diversity after severe flooding in a central Pennsylvania stream. Four months later he found all community measures were significantly lower than pre-flood levels except mean diversity. Based on this measure, Hoopes concluded that the benthic community had recovered. The present study indicates that such a conclusion may be premature, since diversity indices may return to pre-disturbance levels without recovery of pre-disturbance community structure.

Invertebrate Abundance

Mean total benthic density and biomass were significantly greater in the reference stream than in the mining-impacted streams. Most of this difference can be attributed to the impacts of sedimentation.

Reductions in benthic invertebrate abundance as a result of inorganic sedimentation from crushed limestone quarrying (Gammon 1970), lime neutralization of streams (Herricks and Cairns 1974), ferric hydroxide deposition below metallic ore tailings piles (Chadwick 1974), highway construction (Reed 1977), and from mining (Hill 1971; Branson and Batch 1972; Carrithers and Bulow 1973) have been reported. Regardless of the source, inorganic sediment brings about habitat degradation which has been reflected in significant differences in benthic abundance in this study. Rosenberg and Wiens (1975) have hypothesized that benthic reductions following sedimentation result from increased entry into the drift by organisms at the surface and within the affected substrate, coupled with reduced settling and reattachment of drifting organisms from upstream. No upstream areas of the mining-impacted streams in this study were free from the influences of the surface mines, further hindering recolonization.

Benthic density and biomass generally paralleled each other over time but with no clear seasonal pattern among streams. Flooding severely reduced total density and biomass, and recovery to pre-disturbance levels was still incomplete after four months.

Trophic Composition

Benthic invertebrates in the study streams were members of a variety of trophic groups. Analysis of the percentage of the total benthic density and biomass represented by each trophic group and the temporal variation in this parameter yields insight to the functional relationships in each stream.

Collector-gatherers made up the largest and an equivalent part of the benthic density and biomass in the reference stream and in SMS-2. Although this group made up the largest percentage of benthic density in SMS-1, collector-gatherers ranked second in benthic biomass, and both measures were significantly lower than in the other streams. Clearly, collector-gatherers, tied to the detrital food resource, dominated in all three stream systems, indicating the importance of detrital inputs to them (Woodall and Wallace 1972; Webster 1975). The lack of a clear seasonal pattern of abundance was probably due to the broad taxonomic diversity of this group and the stability of the food supply. Trichoptera, which formed the bulk of the collector-filterers, have specific substrate and flow requirements (Edington 1965; Mackay and Kalff 1969; Barber and Kevern 1973) which were apparently not well met in any of the study streams. Predators made up about 8 percent of the benthic density and 15 percent of the benthic biomass in all three streams. The representation of predators changed little over the year. This group apparently found sufficient prey among all of the other invertebrates in each stream. Predators function in lotic systems as both organic particle converters, where the "particles" are actually prey, and as regulators of nonpredator populations (Cummins 1974). Woodrum and Tarter (1973) reported that larvae of a species of the predacious alderfly, Sialis, supplemented its diet with detritus in a stream whose fauna had been sharply reduced by acid mine drainage. This is a good example of the broad flexibility in invertebrate food habits, which may permit certain species to exist in the mining-impacted streams despite less than optimal conditions.

Shredders made up the second largest percentage of the benthos in the impacted streams, but only the fourth largest in the reference stream. Shredders were particularly predominant in SMS-1, where they made up a greater percentage of benthic biomass than any other group. Shredders were dominated by Plecoptera, therefore, the representation of shredders was probably closely linked to LPOM inputs, especially in autumn and early spring.

Scrapers made up the second largest group in the reference stream, with the highest levels in late summer; but scrapers were poorly represented in both of the impacted streams. Scrapers, composed primarily of coleopterans and ephemeropterans, may have been limited by sedimentation in the impacted streams as a result of habitat degradation, food resource reduction, or a combination of the two. The only scraper common in the impacted streams was Hastaperla brevis, a plecopteran capable of scraping algae and other materials from the surfaces of leaves.

Life History

The benthos of the study streams was predominated by forms having rapid or specifically synchronized life cycles which may be of an adaptive advantage in a highly variable environment (Williams and Hynes 1976). The impact of the regularity of stream flows sufficient to cause scouring and increased losses to drift has been discussed. Stream bed freezing as a result of low winter flows coupled with low temperatures can cause high benthic mortality. Such natural conditions in the study streams (i.e. scouring and freezing) certainly act to "disturb" the biotic and abiotic components of the systems and limit the period of habitat stability in which invertebrates may hatch, develop and reproduce.

Elmid and psephenid beetles were the only abundant organisms with life cycles beyond one year in length and were virtually restricted to the reference stream. Their absence from the mining-impacted streams may reflect a greater degree of habitat instability there than in the reference stream. The drastic reduction and slow recovery of all Coleoptera in the reference stream after a major flood indicates their vulnerability to natural catastrophic phenomena. The weak representation of coleoptera fauna in the impacted streams cannot be attributed solely to habitat degradation from sediment deposits, since Gammon (1970) found elmid beetles to be particularly resistant to sediment addition, even though some individuals were literally obscured with a layer of fine material on the body surface. Whether coleopterans have been victims of habitat degradation, food resource degradation, or intolerable environmental fluctuation and substrate instability cannot be determined from this study. The degree to which environmental variation may act to limit the length of the life cycles of the organisms living in a given habitat is poorly understood.

Fish

Taxonomic Composition

The most abundant fish species in the study streams, creek chubs, blacknose dace, and stonerollers, are common inhabitants of headwater streams in southwest Virginia (Hill 1971; Clay 1975; Maughan et al. 1977). Larimore et al. (1959) noted rapid recolonization by stream fish following the return of adequate stream flows after a severe drought. Creek chubs and stonerollers were among the early recolonizers. Hill (1971) found blacknose dace to be the principle reinvader of streams impacted by manganese strip mines. In light of the periodic flushing, freezing, and low flow conditions characteristic of the high gradient, first-order study streams, it is not surprising to find a large proportion of the fish communities represented by species that are "pioneers." Matthews and Styron (1978) has, in fact, demonstrated that headwater species exhibit greater tolerances to fluxes in environmental conditions than do mainstream species, presumably as the result of an evolutionary history in a highly variable environment.

The three dominant species form an energetically partitioned association since they do not directly compete for food resources.

The stoneroller feeds primarily on algae and materials scraped from the substrate (Pflieger 1975), the blacknose dace feeds primarily on aquatic insect larvae (Noble 1965; Small 1975), and the creek chub is a generalized carnivore (Pflieger 1975), able to rely heavily on terrestrial insects which have fallen into the stream (Branson and Batch 1972; Lotrich 1973).

Recolonization by these species, of streams depopulated by mining disturbance, would be expected to occur upon the return of adequate water quality. The poor representation of creek chubs and stonerollers in the mining-impacted headwaters, despite their abundance in the mainstream (Maughan et al. 1977), implies that such recovery has not occurred or is incomplete.

Fantail darters, unique to the mining-impacted streams, and the other infrequently encountered species collected in the reference stream, are probably transient invaders from mainstream areas.

Abundance and Biomass

Branson and Batch (1972), in assessing the effects of strip mining on small-stream fishes in east-central Kentucky, found that fish were progressively eliminated from headwaters downstream, or were forced to emigrate downgrade, and that reproduction in darters and minnows was inhibited by siltation, either by the prevention of reproduction or by fry and egg mortality. Hill (1971) found stream fish populations limited directly and indirectly by high levels of turbidity and siltation when unreclaimed manganese strip mines impacted the watershed. A 50 percent reduction in number and a 10 percent reduction in biomass of fish was attributed to siltation effects in a third-order stream following initiation of strip mining (Lotrich 1973). Lotrich also concluded that fish were, at times, simply displaced from pools due to sediment deposition, rather than from any direct lethal effect.

The significantly lower abundance and biomass of fish in the mining-impacted streams compared to the reference stream is probably the result of several interacting effects linked primarily to sedimentation. The heavy inorganic sediment load reduced the depth and expanse of pools and eliminated much of the instream cover provided by the cobble-boulder substrate. The sediment-mediated reduction in algal diversity and availability as well as the reduction in benthic invertebrate standing crop and increased LPOM transport out of the system decreased available energy to higher trophic levels. Although not evaluated in this study, the trace metals load carried in the water and complexed with fine-particle sediment may have also influenced fish populations.

Since the major recolonizing species present in the mainstream do not interact competitively with regard to food items, none of the species benefits, in terms of food acquisition, from the absence of any of the other species. Coincidence of all three species should result in a much higher level of resource utilization than would occur with a monospecific assemblage. Therefore, the predominance of dace in the mining-impacted streams in itself indicates that fish production was less than optimal.

Seasonal Dynamics

Fish abundance and biomass exhibited a direct relationship to water availability in the present study. The number of species present also increased with high water, especially in spring. Hall (1972) found fish movements to play a major role in the dynamics of fish abundance and composition in headwater streams, with spring being the period of greatest movement. An increase in fish movements, especially upstream, was observed with any appreciable rise in water level, except in winter. Lotrich (1973) found that migrants from higher to lower order streams were associated with high water levels. Downstream migration out of headwaters and into large quiet pools may occur in low flow periods or in winter (Clay 1975).

Flooding reduced fish populations but recovery was rapid, except where physical barriers blocked fish movements. Recovery was probably the result of immigration to headwater streams from more stable mainstream areas. Lotrich (1973) concluded that physical limitations of headwater streams were the most important limiting factor for fish, to the point where some first-order streams would not support fish populations.

Considering the "invader" character of the predominant fish species and the frequency and magnitude of changes in discharge in the study streams, one might view the fish as "habitat opportunists," moving into headwater areas with adequate discharge and descending to more favorable areas under low flow conditions. Such a pattern of movements permits migrants to utilize habitat not generally available to sedentary species (Small 1975).

Observations indicated that the study streams were utilized for reproduction. Hall (1972) found headwaters to be more productive than downstream areas and hypothesized that spawning migrations allowed fish populations to maintain progeny in areas of high productivity. Although young-of-the-year were observed in all streams, differences in spawning success and mortality rates between the mining-impacted streams and the reference stream were not investigated.

SUMMARY AND CONCLUSIONS

1. Large reserves of coal in southwest Virginia have been exploited, leading to extensive land disturbance. Although current law requires that specific reclamation treatments be applied to these disturbed lands, little is known about the effectiveness of such reclamation in ameliorating damages which occur to streams draining mined watersheds. The present evaluation of the affects of reclaimed surface mines on lotic resources required the study of small headwater streams which were subject to more isolated perturbations than high-order streams in southwest Virginia. Knowledge of the functional components and dynamics of these headwaters in their natural state has been inadequate to project the changes to be expected under disturbed conditions.
2. Alkalinity, conductivity, hardness, and sulfate are normally low in southwest Virginia headwaters; however, these chemical measures remained elevated in streams draining mined watersheds, even though reclamation treatment had been applied to the disturbed areas three to five years prior to this study. Increased levels of alkalinity, hardness, and sulfate were directly related to the degree of land disturbance, that is, the greater the percentage of watershed disturbed, the higher were levels of the three chemical characters. Although pH was significantly lower in the mining-impacted streams than in the reference stream, it was only slightly depressed in the former and well within levels compatible for most aquatic life. Low pH is not an important problem in the study area when considering exclusively the $\overset{e}{\textcircled{a}}$ffects

of surface mining. Variation in hardness and sulfate was significantly greater in disturbed-watershed streams than in the reference stream, although variation in alkalinity and pH was equivalent among streams. No clear seasonal or temporal pattern in water quality measures was apparent.

3. The study streams draining mined/reclaimed watersheds reflected a water quality status comparable to a ten-year post-abandonment orphan mine stream, but the former were not as disturbed as those receiving acid mine drainage.
4. The suction-sampling technique provided a numerical index of stream bottom sediment sensitive enough to distinguish differences in the quantity of benthic fine material not apparent by observation alone. The procedure permitted replicate samples to be taken from the same stream areas as those used for biologic collections.
5. Fine inorganic sediment originating from the area of mine disturbance and from abandoned haul roads continually entered the mined watershed streams and resulted in a heavy benthic and suspended burden throughout the study.
6. More fine-particle organic material was held within a given unit area of stream bed in the mining-impacted streams due to entrapment of organic particles in the thick sediment deposits there as compared to the reference stream; however, the organic fraction made up a significantly smaller proportion of the total sediment in the disturbed-watershed streams. The abundance of

inorganic particles in the impacted streams limited the availability of benthic and suspended fine-particle organic material to invertebrate detritivores.

7. Benthic fine-particle organic material represented a significant component of the organic material reservoir in all of the study streams and was not as sharply reduced by flooding as was benthic large-particle organic material.
8. Benthic large-particle organic material standing crop peaked in autumn in all streams, coinciding with the pulsed input of autumn leaf-fall. Storm flows flushed large-particle organic material from the streams and recovery was slow, especially in the disturbed watershed streams. Large-particulate organic material standing crop was significantly greater in the reference stream than in the mining-impacted streams, probably as a result of the smoother substrate in the latter, leading to greater transport of large-particle organic matter out of the disturbed systems.
9. Substantial amounts of large-particle organic material were collected from below the surface of the substrate, suggesting that a subsurface organic material reservoir exists which can gradually release energy to the system over time. Depletion of this subsurface reservoir may occur with severe flooding.
10. The diversity of algal Aufwuchs was lower in the disturbed-watershed streams than in the reference stream, with the flora restricted almost exclusively to diatoms in the former. Ash-free dry weight comparisons of algal Aufwuchs were not feasible due to confounding as a result of the presence of fine detrital

streams and the presence of silt-free rock surfaces in the reference stream.

13. Most of the differences in benthic invertebrate fauna among streams can probably be related to sediment-mediated habitat and food resource degradation. Naturally occurring storm phenomena may limit the benthic fauna of such small, high-gradient streams to species with rapid life cycles or to those species with rapidly developing aquatic stages. Winter freezing appears not to be nearly as deleterious to invertebrate populations as is storm scouring. The paucity of long-lived Coleoptera in the disturbed-watershed streams suggests that natural scouring, freezing, and drying may be more severe there than in the reference stream. Contour surface mining seldom leaves far upstream areas, which may act as reservoirs of recolonizing organisms, free from detrimental effects, thus, slowing the recovery process to both man-caused and natural perturbations.

14. Creek chubs, blacknose dace, and stonerollers were the predominant fish species in the study streams. Recolonization of the mining-impacted streams by these "pioneer" species was apparently still incomplete. Both abundance and biomass of fish were significantly lower in the streams draining mines than in the reference stream. Quality and quantity of habitat was probably limiting to fish in the silt-ladened streams. Movements into and out of the study streams accounted for most of the temporal changes observed. All of the study streams were utilized for spawning and reproduction.

In conclusion, it is apparent that small, high-gradient streams, such as the study streams, are subject to natural perturbation resulting from broad environmental fluxes. These fluxes probably result in a greater degree of disturbance in streams draining mined lands. Since environmental variations can quickly alter biotic populations and the standing crop of organic particulate matter in streams, and since many of the fish and benthic invertebrates may be characterized as pioneers, a study to assess headwater stream conditions must include frequent sampling. The dramatic influence that environmental variations have on biotic populations may limit the role of interspecific competition in population regulation, so that much of the time, traditional models may not be applicable to the dynamics of headwaters.

It was found that, on the basis of abiotic and biotic measures, the disturbed-watershed streams were in a "poorer" condition than the reference stream despite reclamation treatment. In addition, the two mining-impacted streams were dissimilar from each other in many respects, despite the fact that they drained the same mine. The overall condition of the streams draining mines having received reclamation treatment three to five years prior to this study was little better than for streams which drained mined watersheds abandoned without reclamation about 10 years earlier.

The present study is unable to predict future gains in water quality recovery as a direct result of the reclamation treatments; however, the recovery process is obviously a very slow one. Only further study can document the progress of the mine-impacted stream recovery from contour mining perturbations.

The classic acid mine drainage model may not be adequate to describe the changes brought about solely by surface mining in this geographical area. A clear analysis of the mining perturbations problem may rely, in part, on the maintenance of the distinction between the terms "strip mining" and "acid mine drainage." This investigation points to continued sedimentation as a more serious and pervasive concern than acid formation when dealing with surface mining and its effects on streams in southwest Virginia.

It is apparent that terrestrial reclamation is not equivalent to lotic reclamation and recovery. When only a very small percentage of a watershed is left in a disturbed condition, substantial erosional inputs to streams can occur. Therefore, what might be considered to be acceptable vegetative coverage may still result in little appreciable benefit to streams in the watershed. The inclusion of water quality criteria in the administration of mined-land reclamation would be beneficial in closing the apparent gap between terrestrial and aquatic recovery from mining disturbances. Failure to adjust reclamation procedures so as to enhance stream recovery will not only limit optional uses of the immediate resource, but will also add to water quality degradation far downstream, ultimately reducing the net public benefit of the coal extracted from mined lands.

REFERENCES CITED

American Public Health Association, American Water Works Association and Water Pollution Control Federation. 1975. Standard methods for the examination of water and wastewater. 14th edition. American Public Health Association, Washington, D.C. 1193 pp.

Anderson, N. H., and D. M. Lehmkuhl. 1968. Catastrophic drift of insects in a woodland stream. Ecology 49:198-206.

Attiwill, P. M. 1968. The loss of elements from decomposing litter. Ecology 49:142-145.

Baker, R. A., and A. G. Wilshire. 1970. Microbiological factor in acid mine drainage formation: a pilot plant study. Environ. Sci. Technol. 4(5):401-407.

Barber, W. E., and N. R. Kevern. 1973. Ecological factors influencing macroinvertebrate standing crop distribution. Hydrobiologia 43:53-75.

Boling, R. H., Jr., E. D. Goodman, J. A. VanSickle, J. O. Zimmer, K. W. Cummins, R. C. Petersen, and S. R. Reice. 1975. Toward a model of detritus processing in a woodland stream. Ecology 56(1):141-151.

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.

Cairns, J., Jr., J. S. Crossman, K. L. Dickson, and E. E. Herricks. 1971. The recovery of damaged streams. Assoc. Southeastern Biol. Bull. 18(3):79-106.

Carle, F. L. 1976. An evaluation of the removal method for estimating benthic populations and diversity. M.S. Thesis, Virginia Polytech. Inst. and State Univ. 110 pp.

Carle, F. L., and M. R. Strub. 1978. A new method for estimating population size from removal data. Biometrics (in press).

Carrithers, R. B., and F. J. Bulow. 1973. An ecological survey of the West Fork of the Obey River, Tennessee with emphasis on the effects of acid mine drainage. J. Tenn. Acad. Sci. 48(2):65-72.

Chadwick, J. W. 1974. The effects of iron on the macroinvertebrates of Soda Butte Creek. M.S. Thesis. Montana State Univ. 39 pp.

Clay, W. M. 1975. The fishes of Kentucky. Kentucky Dept. of Fish and Wildlife Resour., Frankfort, Ky. 416 pp.

Connell, J. F., D. N. Contractor, and V. O. Shanholtz. 1976. Factors affecting water quality from strip-mined sites. Virginia Water Resour. Res. Bull. 87. Blacksburg, Va. 75 pp.

Cordone, A. J., and D. W. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. Cal. Fish and Game 47(2):189-228.

Cummins, K. W. 1973. Trophic relations of aquatic insects. Ann. Rev. Ent. 18:183-206.

Cummins, K. W. 1974. Structure and function of stream ecosystems. Bioscience 24(11):631-641.

Cummins, K. W., M. J. Klug, R. G. Wetzel, R. C. Petersen, K. F. Suberkropp, B. A. Manny, J. C. Wuycheck, and F. D. Howard. 1972. Organic enrichment with leaf leachate in experimental lotic ecosystems. Bioscience 22:719-722.

Cummins, K. W., R. C. Petersen, F. O. Howard, J. C. Wuycheck, and V. I. Holt. 1973. The utilization of leaf litter by stream detritivores. Ecology 54(2):336-345.

Curtis, W. R. 1973. Effects of strip mining on the hydrology of small mountain watersheds in Appalachia. Pages 145-157 in R. J. Hutnik and G. Davis, eds. Ecology and reclamation of devastated land. Vol. 1. Gordon and Breach, New York, N.Y.

De la Cruz, A. A., and A. H. Post. 1977. Production and transport of organic matter in a woodland stream. Arch. Hydrobiol. 80(2): 227-238.

Dietrich, R. V. 1970. Geology and Virginia. Univ. Press of Virginia, Charlottesville, Va. 213 pp.

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

Dubois, M., K. A. Gilles, J. K. Hamilton, P. A. Rebers, and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Analyt. Chem. 28(3):350-356.

Dyer, K. L., and W. R. Curtis. 1977. Effect of strip mining on water quality in small streams in eastern Kentucky, 1967-1975. N.E. For. Exp. Stn., Upper Darby, Pa. 13 pp.

Edington, J. M. 1965. The effect of water flow on populations of net spinning Trichoptera. Mitt. int Verein. Theor. Angew. Limnol. 13:40-48.

Egglishaw, H. J. 1964. The distributional relationship between the bottom fauna and plant detritus in streams. J. Anim. Ecol. 33:463-476.

Egglishaw, H. J., and P. E. Shackley. 1971. Suspended organic matter in fast-flowing streams in Scotland. I. Downstream variations in microscopic particles. Freshwater Bio. 1:273-286.

Ehrenfeld, D. W. 1976. The conservation of non-resources. Am Sci. 64(6):648-656.

Fisher, S. G., and G. E. Likens. 1973. Energy flow in Bear Brook, New Hampshire: an integrative approach to stream ecosystem metabolism. Ecol. Monogr. 43(4):421-439.

Funk, J. L. 1957. Movement of stream fishes in Missouri. Trans. Am. Fish Soc. 85:39-57.

Gammon, J. R. 1970. The effect of inorganic sediment on stream biota. U.S. Environ. Protect. Agency, Water Pollut. Control Res. Ser. 18050 DWC 12/70. 141pp.

Gaufin, A. R. 1973a. Water quality requirements of aquatic insects. U.S. Environ. Protect. Agency, Ecol. Res. Ser. 660/3-73-004, Washington, D.C. 89pp.

Gaufin, A. R. 1973b. Use of aquatic invertebrates in the assessment of water quality. Pages 96-116 in Biological methods for the assessment of water quality, ASTM Special Tech. Publ. 528. American Society for Testing and Materials, Philadelphia, Pa.

Goodman, D. 1975. The theory of diversity-stability relationships in ecology. Q. Rev. Biol. 50(3):237-266.

Hach Chemical Company. 1975. Procedures, chemical lists and glassware for water and wastewater analysis. Hach Chemical Company, Ames, Iowa. 186pp.

Hall, C. A. 1972. Migration and metabolism in a temperate stream ecosystem. Ecology 53:585-604.

Herricks, E. E., and J. Cairns, Jr. 1974. Rehabilitation of streams receiving acid mine drainage. Virginia Polytech. Inst. and State Univ. Water Resour. Res. Bull. 66. 284pp.

Hesser, R., R. Hoopes, C. B. Weirich, J. Selchen, B. Hollender, and R. Snyder. 1975. Chapter 2, The aquatic biota. Pages 9-20 in Clearcutting in Pennsylvania. The Pennsylvania State University School of Forest Resources, University Park, Pa.

Hill, D. M. 1971. Stream faunal recovery after manganese strip mine reclamation. Ph.D. Thesis. Virginia Polytech. Inst. and State Univ. (Libr. Congr. Card No. Mic. 72-16289). 73pp. University Microfilms. Ann Arbor, Mich.

Hilsenhoff, W. L. 1975. Aquatic insects of Wisconsin. Tech. Bull. No. 89, Wisconsin Dept. of Nat. Resour., Madison, Wisc. 52pp.

Hollander, M., and D. A. Wolfe. 1973. Nonparametric statistical methods. John Wiley and Sons, New York, N.Y. 503pp.

Hoopes, R. L. 1975. Flooding, as the result of Hurricane Agnes, and its effect on a macrobenthic community in an infertile headwater stream in central Pennsylvania. Limnol. Oceanogr. 19:853-857.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. of Toronto Press, Toronto, Canada. 555pp.

Hynes, H. B. N. 1975. The stream and its valley. Verh. Internat. Verein. Limnol. 19:1-15.

Karlström, U., and S. Backlund. 1977. Relationship between algal cell number, chlorophyll a, and fine particulate organic matter in a river in northern Sweden. Arch. Hydrobiol. 80(2):192-199.

Kaushik, N. K., and H. B. N. Hynes. 1968. Experimental study of the role of autumn-shed leaves in aquatic environments. J. Ecol. 56:229-243.

Kaushik, N. K., and H. B. N. Hynes. 1971. The fate of the dead leaves that fall into streams. Arch. Hydrobiol. 69(4):465-515.

Krumholz, L. A., and S. E. Neff. 1970. The freshwater stream, a complex ecosystem. Water Resour. Bull. 6(1):163-174.

Larimore, R. W., W. F. Childers, and C. Heckrotte. 1959. Destruction and re-establishment of stream fish and invertebrates affected by drought. Trans. Am. Fish. Soc. 88(4):261-285.

Lock, M. A., and H. B. N. Hynes. 1976. The fate of "dissolved" organic carbon derived from autumn-shed maple leaves (Acer saccharum) in a temperate hardwater stream. Limnol. Oceanogr. 21(3):436-443.

Lotrich, V. A. 1973. Growth, production, and community composition of fishes inhabiting a first-, second-, and third-order stream of eastern Kentucky. Ecol. Monogr. 43(3):377-397.

Lush, D. L., and H. B. N. Hynes. 1973. The formation of particles in freshwater leachates of dead leaves. Limnol. Oceanogr. 18:968-977.

Lynch, J. A., E. S. Corbett, and R. Hoopes. 1977. Implications of forest management practices on the aquatic environment. Fisheries 2(2):16-22.

Mackay, R., and J. Kalff. 1969. Seasonal variation in standing crop and species diversity of insect communities in a small Quebec stream. Ecology 50:101-109.

Mathews, C. P., and A. Kowalczewski. 1969. The disappearance of leaf litter and its contribution to production in the River Thames. J. Ecol. 57:543-552.

Matter, W. J., J. J. Ney, and O. E. Maughan. 1978. Sustained impact of abandoned surface mines on fish and benthic invertebrate populations in headwater streams of southwestern Virginia. Presented at the 1978 N.E. Fish and Wildl. Conf., 26 Feb.-1 March, White Sulphur Springs, W. Va. (abstract published).

Matthews, W. J., and J. T. Styron, Jr. 1978. Comparative tolerance of headwater and mainstream fishes for abrupt change in pH, dissolved oxygen, and temperature. Submitted to Trans. Am. Fish. Soc.

Maughan, O. E., W. J. Matter, and L. R. Peltz. 1977. Reclamation needs of abandoned surface mines: fisheries section completion report. U.S. Fish Wildl. Serv. Proj. Rep. 201pp. Xerox.

McDowell, W. H., and S. G. Fisher. 1976. Autumnal processing of dissolved organic matter in a small woodland stream ecosystem. Ecology 57(3):561-569.

Merritt, R. W., and K. W. Cummins, eds. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co., Dubuque, Iowa. 441pp.

Minear, R. A., and B. A. Tschantz. 1976. The effect of coal surface mining on the water quality of mountain drainage basin streams. J. Water Pollut. Contr. Fed. 48(11):2549-2569.

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

Nelson, D. J., and D. C. Scott. 1962. Role of detritus in the productivity of a rock-outcrop community in a piedmont stream. Limnol. Oceanogr. 7:396-413.

Nichols, L. E., Jr., and F. J. Bulow. 1973. Effects of acid mine drainage on the stream ecosystem of the East Fork of the Obey River, Tennessee. J. Tenn. Acad. Sci. 48(1):30-39.

Noble, R. L. 1965. Life history and ecology of western Blacknose Dace, Boone County, Iowa, 1963-1964. Iowa Acad. Sci. 72:282-293.

Odum, E. P. 1971. Fundamentals of ecology. W. B. Saunders Co., Philadelphia, Pa. 574pp.

Patrick, R. 1978. Effects of tracemmetals in the aquatic ecosystem. Am. Sci. 66(2):185-191.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Dept. of Conservation. 343pp.

Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. J. Theoret. Biol. 13:131-144.

Piric, W. R., and W. A. Hubert. 1977. Assumptions in statistical analysis. Trans. Am. Fish. Soc. 106(6):646-648.

Plass, W. T. 1967. Survey of eastern Kentucky. Kentucky Dept. of Nat. Resour., Presented at the Strip Mining Symposium, 13-14 July, 1967, Owensboro, Ky.

Porter, K. G. 1977. The plant-animal interface in freshwater ecosystems. Am. Sci. 65(2):159-170.

Reed, J. R., Jr. 1977. Stream community response to road construction sediments. Virginia Polytech. Inst. and State Univ. Water Resour. Res. Bull. 97. 61pp.

Rosenberg, D. M., and A. P. Wiens. 1975. Experimental sediment addition studies on the Harris River, N.W.T., Canada: The effect on macro-invertebrate drift. Verh. Internat. Verein. Limnol. 14:1568-1574.

Saul, G. E., P. E. Schilling, and K. L. Koonce. 1978. Assumptions, statistical methodologies and fisheries: a problem to be considered. Presented at the 1978 N.E. Fish and Wildl. Conf., 26 Feb.-1 March, White Sulphur Springs, W. Va. (abstract published).

Siegfried, C. A., and A. W. Knight. 1977. The effects of washout in a foothill stream. Am. Midl. Nat. 98(1):200-206.

Simmons, G. M., Jr. 1972. A preliminary report on the use of the sequential comparison index to evaluate acid mine drainage on the macrobenthos in a pre-impoundment basin. Trans. Am. Fish. Soc. 101(4):701-713.

Small, J. W., Jr. 1975. Energy dynamics of benthic fishes in a small Kentucky stream. Ecology 56(4):827-840.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco, Ca. 776pp.

Sorensen, D. L., M. M. McCarthy, E. J. Middlebrooks, and D. B. Porcella. 1977. Suspended and dissolved solids affects of freshwater biota: A review. U.S. Environ. Protect. Agency, Ecol. Res. Ser. 600/3-77-042, Washington, D.C. 73pp.

Suberkropp, K., and M. J. Klug. 1976. Fungi and bacteria associated with leaves during processing in a woodland stream. Ecology 57(4):707-719.

Tebo, L. B., Jr. 1955. Effects of siltation resulting from improper logging on the bottom fauna of a small trout stream in the southern Appalachians. Prog. Fish-Cult. 17(2):64-70.

Triska, F. J. 1970. Seasonal distribution of aquatic hyphomycetes in relation to the disappearance of leaf litter from a woodland stream. Ph.D. Thesis. Univ. of Pittsburgh. 189pp.

Waters, T. F., and R. J, Knapp. 1961. An improved stream bottom fauna sampler. Trans. Am. Fish. Soc. 90:225-226.

Weber, C. I., ed. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. U.S. Environ. Protect. Agency, Environ. Monitoring Ser. 670/4-73-001, Washington, D.C. 173pp.

Webster, J. R. 1975. Analysis of potassium and calcium dynamics in stream ecosystems on three southern Appalachian watersheds of contrasting vegetation. Ph.D. Thesis. Univ. of Georgia. 222pp.

Weigle, W. K. 1966. Erosion from abandoned coal-haul roads. J. Soil and Water Conserv. 21(3):98.

Williams, D. D., and H. B. N. Hynes. 1977. Benthic community development in a new stream. Can. J. Zool. 55(7):1071-1076.

Woodall, W. R., and J. B. Wallace. 1972. The benthic fauna in four small Southern Appalachian streams. Am. Midl. Nat. 88:393-407.

Woodrum, J. E., and D. C. Tarter. 1973. The life history of the alderfly, Sialis aequalis Banks, in an acid mine stream. Am Midl. Nat. 89(2):360-368.

APPENDIX

Appendix Table I. Trophic group assignments, according to Merritt and Cummins (1978), to the benthic invertebrate taxa collected from three southwest Virginia headwater streams.

Collector-gatherers	Collector-filterers	Predators	Shredders	Scrapers
Nematoda	Trichoptera	Hydracarina	Plecoptera	Plecoptera
	Cheumatopsyche		Allocapnia	Hastaperla
Oligochaeta	Diplectrona	Plecoptera	Amphinemura	Strophopteryx
	Hydropsyche	Acroneuria	Leuctra	
Decapoda	Wormaldia	Isogenus	Nemoura	Ephemeroptera
		Isoperla	Peltoperla	Pseudocloeon
Ephemeroptera	Diptera		Taeniopteryx	
Ameletus	Simuliidae	Odonata		Trichoptera
Baetis	Simulium	Boyeria	Trichoptera	Agapetus
Baetisca	Prosimulium	Cordulegaster	Lepidostoma	Goera
Caenis		Hetaerina	Neophylax	
Centroptilum	Pelecypoda	Stylogomphus	Pseudostenophylax	
Epeorus	Sphaerium		Pycnopsyche	
Ephemerella		Megaloptera		Coleoptera
Habrophleboides	Ephemeroptera	Nigronia	Coleoptera	Ectoparia
Heptagenia	Isonychia	Sialis	Hydrochus	Helichus
Leptophlebia				Psephenus
Paraleptophlebia		Trichoptera	Diptera	
Stenacron		Polycentropus	Chironomidae	
Stenonema		Rhyacophila	Brillia	
			Polypedilum	
Trichoptera		Coleoptera	Tipulidae	
Agraylea		Hydrobius	Limnobiinae	
Lype			Tipula	

Appendix Table I. Trophic group assignments, according to Merritt and Cummins (1978), to the benthic invertebrate taxa collected from three southwest Virginia headwater streams. (continued)

Collector-gatherers	Collector-filterers	Predators	Shredders	Scrapers
Coleoptera		Diptera		
Dubiraphia		Anthyomiidae		
Optioservus		Ceratopogonidae		
Oulimnius		*Palpomyia*		
Stenelmis				
		Chironomidae		
Diptera		*Tanypodinae*[1]		
Ceratopogonidae				
Atrichopogon		Dolichopodidae		
Dasyhelea				
Forcipomyia		Tipulidae		
Chironomidae		*Dicranota*		
Chironomini[2]		*Eriopterini*		
Orthocladinae[3]		*Hexatoma*		
Tanytarsini[1]		*Limnophila*		
Dixidae		*Pseudolimnophila*		
Dixa				
Empididae				
Psychodidae				
Pericoma				
Tabanidae				
Chrysops				

[1] all genera collected

[2] except *Cryptochironomus* and *Polypedilum*

[3] except *Brillia*

Appendix Table II. The lowest taxonomic level identified for benthic invertebrates, and a relative abundance ranking based on collections from three southwest Virginia headwater streams from December 1975 through August 1977.

Taxa	Reference Stream	SMS-1	SMS-2
Phylum Nematoda	A	C	C
Phylum Annelida			
Class Oligochaeta			
Order Prosopora			
Family Branchiobdellidae	C	R	R
Family Lumbriculidae	A	A	A
Order Plesiopora			
Family Naididae	C	R	R
Phylum Arthropoda			
Class Crustacea			
Order Decapoda			
Family Astacidae			
Cambarus	C	C	C
Orconectes	C		
Class Arachnoidea			
Order Hydracarina	C		
Class Insecta			
Order Plecoptera			
Family Capniidae			
Allocapnia	R	R	R
Family Chloroperlidae			
Hastaperla brevis	C	A	A
Family Leuctridae			
Leuctra (possibly *L. ferruginea*)	A	A	A
Family Nemouridae			
Amphinemura delosa	R	R	R
Nemoura (primarily *N. truncata*)	C	C	C
Family Peltoperlidae			
Peltoperla		R	
Family Perlidae			
Acroneuria carolinensis	C	R	R
A. xanthenes		R	R
Family Perlodidae			
Isogenus[1]		R	
Isoperla[2]	C	C	C

Appendix Table II. The lowest taxonomic level identified for benthic invertebrates, and a relative abundance ranking based on collections from three southwest Virginia headwater streams from December 1975 through August 1977. (continued)

Taxa	Reference Stream	SMS-1	SMS-2
Family Taeniopterygidae			
Strophopteryx fasciata	R		
Taeniopteryx	R		
Order Ephemeroptera			
Family Baetidae			
Baetis		C	C
Centroptilum	C	C	C
Pseudocloeon	R	R	R
Family Baetiscidae			
Baetisca carolina	C		
Family Caenidae			
Caenis	A		R
Family Ephemerellidae			
Ephemerella subg. Drunella *cornutella*	C		R
E. subg. Ephemerella[3]		R	R
E. subg. Eurylophella *minimella*	A	R	C
E. subg. Serratella *frisoni*	R	R	R
Family Ephemeridae			
Ephemera varia	A	R	C
Family Heptageniidae			
Epeorus subg. Iron	C	R	R
Heptagenia	R		
Stenacron[4]	C	R	R
Stenonema[5]	A	C	C
Family Leptophlebiidae			
Habrophleboides	R		
Leptophlebia	R		
Paraleptophlebia[6]	A	C	C
Family Sipholonuridae			
Ameletus lineatus	C	C	C
Isonychia	R		
Order Odonata			
Family Aeshnidae			
Boyeria	R		R
Family Cordulegasteridae			
Cordulegaster	R	R	R

Appendix Table II. The lowest taxonomic level identified for benthic invertebrates, and a relative abundance ranking based on collections from three southwest Virginia headwater streams from December 1975 through August 1977. (continued)

Taxa	Reference Stream	SMS-1	SMS-2
Family Gomphidae			
Stylogomphus albistylus	C		R
Family Agrionidae			
Hetaerina			R
Order Megaloptera			
Family Corydalidae			
Nigronia serricornis	R	R	R
Family Sialidae			
Sialis	C	R	C
Order Trichoptera			
Family Glossosomatidae			
Agapetus		R	R
Family Goeridae			
Goera	R		
Family Hydropsychidae			
Cheumatopsyche	C	C	C
Diplectrona modesta	R	C	C
Hydropsyche slossonae	C	C	C
Family Hydroptilidae			
Agraylea	R	R	
Family Lepidostomatidae			
Lepidostoma	R		
Family Limnephilidae			
Neophylax		R	
Pseudostenophylax	C	C	C
Pycnopsyche	R	R	R
Family Philopotamidae			
Wormaldia			R
Family Psychomyiidae			
Lype diversa	R	R	R
Polycentropus	R		R
Family Rhyacophilidae			
Rhyacophila vibox			R
Order Coleoptera			
Family Dryopidae			
Helichus (adults & larvae)	C		R

Appendix Table II. The lowest taxonomic level identified for benthic invertebrates, and a relative abundance ranking based on collections from three southwest Virginia headwater streams from December 1975 through August 1977. (continued)

Taxa	Reference Stream	SMS-1	SMS-2
Family Elmidae			
Dubiraphia (adults & larvae)	R		R
Optioservus (adults & larvae)	A	R	R
Oulimnius latisculus (adults & larvae)	A		
Stenelmis (adults & larvae)	R		
Family Hydrophilidae			
Hydrobius		R	R
Hydrochus			R
Family Psephenidae			
Ectoparia	C		
Psephenus herricki	A	R	C
Order Diptera			
Family Anthomyiidae (possibly *Limnophora*)			R
Family Ceratopogonidae			
Atrichopogon (species A and B)	R	R	R
Dasyhelea	R	R	R
Forcipomyia	R	R	
Palpomyia (or closely related)	C	C	C
Family Chironomidae			
subf. Chironominae			
Chironomus	R	R	R
chironomid genus A	C		
Cryptochironomus	C	R	R
Dicrotendipes	R		R
Kiefferulus	R	R	
Microspectra	A	A	A
Microtendipes	A	C	C
Paratendipes	R	R	R
Phaenopsectra	R	R	
Polypedilum	C	C	C
Pseudochironomus	C	C	R
Rheotanytarsus	R		
Stictochironomus	R		
subf. Orthocladinae			
Brillia	R		
Cardiocladius	R		R
Cricotopus	C	R	R
Epoicocladius	C	R	

Appendix Table II. The lowest taxonomic level identified for benthic invertebrates, and a relative abundance ranking based on collections from three southwest Virginia headwater streams from December 1975 through August 1977. (continued)

	Reference Stream	SMS-1	SMS-2
Heterotrissocladius	C	C	C
Orthocladius	A	A	A
Parametriocnemus	R	R	R
Pseudosmittia	R	R	
Rheocricotopus	R	R	R
Smittia	R	R	
Thienemanniella	C	C	C
Trichocladius		R	
subf. Tanypodinae			
Ablabesmyia	C	C	C
Coelotanypus	R		
Zavrelimyia	C	C	C
Family Dixidae			
Dixa		R	R
Family Dolichopodidae	R		R
Family Empididae (possibly *Hemerodromia*)	R	R	R
Family Psychodidae			
Pericoma	R	R	R
Family Simulidae			
Prosimulium	R		
Simulium	R	R	R
Family Tabanidae			
Chrysops		R	R
Family Tipulidae			
Antocha	C	R	R
Dicranota	R	C	C
Hexatoma	C	C	C
Limnophila		R	R
Pseudolimnophila	C	R	
Tipula	C	C	C
unidentified Limnobiinae	R	R	R
unidentified Limniiae	R	C	C
Class Pelecypoda			
Family Sphaeriidae			
Sphaerium	R		

Appendix Table II. The lowest taxonomic level identified for benthic invertebrates, and a relative abundance ranking based on collections from three southwest Virginia headwater streams from December 1975 through August 1977. (continued)

A = abundant, occurring in most collections in high numbers (50/m^2)
C = common, occurring in at least half of the collections and in moderate numbers
R = rare, occurring in only a few collections and never more than one or two individuals per square meter

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1 possibly *I. duplicatus* or *I. decisus*
2 primarily an unidentified species with a few *I. clio* and *I. orata*
3 including *E. invaria*, *E. dorothea*, and *E. rotunda*
4 *S. carolina* and an unidentified species
5 primarily *S. vicarium* and a few *S. rubrum* and *S. tripunctatum*
6 primarily *P. mollis* and only a few individuals of an unidentified species

Appendix Table III. Mean benthic invertebrate density (number/0.26 m^2) in three southwest Virginia headwater streams from December 1975 through August 1977.

Date	Reference Stream	SMS-1	SMS-2
12/75	394	1284	387
3/76	520	264	62
6/76	426	144	108
7/76	692	233	138
8/76	2320	154	452
9/76	962	36	1197
10/76	738	131	362
11/76	822	138	234
3/77	441	119	132
4/77	48	24	12
5/77	134	281	196
6/77	168	306	36
7/77	161	78	83
8/77	282	104	176

Appendix Table IV. Mean benthic invertebrate biomass ($g/0.26\ m^2$, wet weight) in three southwest Virginia headwater streams from December 1975 through August 1977.

Date	Reference Stream	SMS-1	SMS-2
12/75	0.722	0.912	1.344
3/76	2.098	0.498	0.164
6/76	0.670	0.078	0.134
7/76	1.138	0.279	0.202
8/76	2.031	0.052	0.081
9/76	0.755	0.770	1.146
10/76	1.174	0.803	0.242
11/76	1.180	0.614	0.958
3/77	1.180	0.638	0.438
4/77	0.175	0.024	0.010
5/77	0.161	0.062	0.070
6/77	0.202	1.561	0.046
7/77	0.276	0.263	0.258
8/77	0.337	0.100	0.170

VITA

William John Matter was born in St. Cloud, Minnesota on November 5, 1950. He attended local grade schools in St. Cloud and graduated from St. Cloud Technical High School in 1969.

He enrolled in St. Cloud State University in the fall of 1969, attended St. John's University, Collegeville, Minnesota during his junior year, and returned to St. Cloud State University, receiving his Bachelor of Arts degree in Biology in 1973 and his Master of Science degree in Biology in 1975. Mr. Matter became a candidate for the Doctor of Philosophy degree in Fisheries and Wildlife Sciences at Virginia Polytechnic Institute and State University in July 1975.

One June 23, 1973, Mr. Matter married the former Jane N. Nemanick of Eveleth, Minnesota.

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THE STATUS AND SEASONAL DYNAMICS OF FISH AND BENTHIC INVERTEBRATE POPULATIONS IN RELATION TO ORGANIC AND INORGANIC MATERIAL INPUTS AND SURFACE MINING IMPACTS IN THREE VIRGINIA HEADWATER STREAMS

by

William John Matter

(ABSTRACT)

Study of two streams impacted by surface-mining and a similar unimpacted reference stream demonstrated that alkalinity, conductivity, hardness, and sulfate were elevated in the former despite reclamation treatment of the watersheds three to five years earlier. The mined-watershed streams carried a heavy benthic sediment burden, due primarily to the continued erosion from the mined areas and from abandoned haul roads. Inorganic sediment in the mining-impacted streams covered the natural rubble substrate, smoothing the bottom, filling in pools, and impacting the processing of allochthonous organic material, the principal energy source. Fine-particle organic material was trapped in the sediment, but density of larger particles was reduced, possibly due to increased transport over the smoothed substrate.

Benthic invertebrate and fish density, biomass, and diversity were consistently lower in the mining-impacted streams. The pattern of fish and benthic invertebrate recovery following a major flood was slow but unique in all streams. The benthic and fish communities

of headwater streams are naturally subject to decimation by flooding, but sediment-mediated habitat and food degradation may further limit invertebrate and fish populations in disturbed systems.

This study demonstrates that sedimentation can be a severe and long-term after-effect of surface mining, even in the absence of acid drainage. Terrestrial reclamation did not result in lotic reclamation and recovery. The inclusion of water quality criteria in the administration of mined-land reclamation would promote terrestrial management practices conducive to aquatic systems recovery.