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Benthic Invertebrate Communities and Their Responses to Selected Environmental Factors in the Kanawha River Basin, West Virginia, Virginia, and North Carolina

National Water-Quality Assessment Program

Water-Resources Investigations 01-4021

U.S. Department of the Interior
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By Douglas B. Chambers and Terence Messinger

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National Water-Quality Assessment Program

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Cover photo: Heptageniidae Mayfly nymph. Photo by Howell Daly, printed with permission of the North American Benthological Society.

Foreword

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings.

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, VERTICAL DATUM, WATER-QUALITY UNITS, AND OTHER ABBREVIATIONS

Multiply	By	To obtain
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon (gal)	3.785	liter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
fluid ounce	29.57	milliliter (mL)
pound (lb)	0.4536	kilogram
square mile (mi2)	2.590	square kilometer
square foot	0.0929	square meter

Temperature in degrees Celsius (oC) can be converted to degrees Fahrenheit (oF), and conversely, by the following equations:

oF = (1.8 x oC) + 32 oC = (oF – 32) x 0.5555

Vertical datum: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units: Chemical concentrations and water temperature are given in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (mg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

OTHER ABBREVIATIONS, ACRONYMS, AND SYMBOLS USED IN THIS REPORT

CCA	Canonical Correspondence Analysis
DCA	Detrended Correspondence Analysis
EPT	Ephemeroptera, Plecoptera, and Trichoptera
MRLC	Multi-Resolution Land Characteristics
NAWQA	National Water-Quality Assessment Program
TWINSPAN	Two-Way INdicator SPecies ANalysis
USGS	U. S. Geological Survey
WMA	Wildlife Management Area
>	greater than
<	less than

Benthic Invertebrate Communities and Their Responses to Selected Environmental Factors in the Kanawha River Basin, West Virginia, Virginia, and North Carolina

by Douglas B. Chambers and Terence Messinger

Abstract

The effects of selected environmental factors on the composition and structure of benthic invertebrate communities in the Kanawha River Basin of West Virginia, Virginia and North Carolina were investigated in 1997 and 1998. Environmental factors investigated include physiography, land-use pattern, streamwater chemistry, streambed-sediment chemistry, and habitat characteristics. Land-use patterns investigated include coal mining, agriculture, and low intensity rural-residential patterns, at four main stem and seven tributary sites throughout the basin. Of the 37 sites sampled, basin size and physiography most strongly affected benthic invertebrate-community structure.

Land-use practices also affected invertebrate community structure in these basins. The basins that differed most from the minimally affected reference condition were those basins in which coal mining was the dominant nonforest land use, as determined by comparing invertebrate-community metric values among sites. Basins in which agriculture was important were more similar to the reference condition.

The effect of coal mining upon benthic invertebrate communities was further studied at 29 sites and the relations among invertebrate communities and the selected environmental factors of land use, streamwater chemistry, streambed-sediment chemistry, and habitat characteristics analyzed. Division of coal-mining synoptic-survey sites based on invertebrate-community composition resulted in two groups—one with more than an average production of 9,000 tons of coal per square mile per year since 1980, and one with lesser or no recent coal production. The group with significant recent coal production showed higher levels of community impairment than the group with little or no recent coal production. Median particle size of streambed sediment, and specific conductance and sulfate concentration of streamwater were most strongly correlated with effects on invertebrate communities. These characteristics were related to mining intensity, as measured by thousands of tons of coal produced per square mile of drainage area.

INTRODUCTION

Complex interactions of the physical and chemical environments of streams affect benthic invertebrate community structure in the Kanawha River Basin, as they do elsewhere. Geology, physiography, and land-use patterns in a basin directly affect the stream environments, thereby indirectly influencing invertebrate communities. Historically, land use in the Kanawha River Basin has included agriculture, forestry, oil and gas production, brine and salt production, chemical manufacturing, and coal mining (Messinger and Hughes, 2000). Currently (2000), coal mining has impaired more stream miles in the Kanawha River

Basin than any other land use (West Virginia Division of Environmental Protection, 303d report, 1998). Coal-mining effects include increased sedimentation, alteration of streamwater chemistry, and landscape-scale changes in geomorphology. Some of these effects can continue for decades after mining ceases.

Fecal matter, from both human and animal sources, degrades streams through the introduction of nutrients and pathogens. The contamination enters streams as either untreated sewage, the result of inadequate wastewater treatment for the basin's decentralized population, or as agricultural runoff from pastures and feedlots. Other agricultural effects upon streams include pesticide and fertilizer runoff, erosion from heavily grazed fields, and loss of riparian habitat. Other significant, although generally localized, environmental effects are caused by logging, chemical manufacturing, industrial activities, and urbanization.

As part of the National Water-Quality Assessment (NAWQA) Program, the U. S. Geological Survey (USGS) investigated the effects of selected environmental factors upon benthic invertebrate communities in the Kanawha River Basin of West Virginia, Virginia and North Carolina (fig 1.). The goal of the NAWQA Program is to describe the status and trends in the quality of the ground- and surface-water resources of the United States and to develop an understanding of the natural and human factors that affect these resources (Hirsch and others, 1988). Ecological investigations are an important component of the NAWQA Program.

Description of the Kanawha River Basin

The Kanawha River Basin (fig. 1) drains 12,223 mi^2 in North Carolina, Virginia, and West Virginia (Messinger and Hughes, 2000). The Kanawha River forms at the confluence of the New and Gauley Rivers. The New River, the major tributary of the Kanawha River, originates in North Carolina. Major tributaries (> 400 mi^2) of the New River are the Bluestone and Greenbrier Rivers in West Virginia. Other major tributaries of the Kanawha River are the Elk and Coal Rivers. The Kanawha River drains to the Ohio River at Point Pleasant, W. Va.

The Kanawha River drains parts of three physiographic provinces —the Appalachian Plateaus Province (7,334 mi^2), Valley and Ridge Province (2,811 mi^2), and the Blue Ridge Province (2,078 mi^2) (Fenneman, 1938). The headwaters of the Kanawha River are in the Blue Ridge, and the New River is the only major river that flows north from the Blue Ridge through the Valley and Ridge and into the Appalachian Plateaus. Hilltop altitude in the Appalachian Plateaus ranges from about 1,000 ft to about 4,000 ft, generally from northwest to east and southeast, and relief is generally greater in the area with greater altitude.

The climate of the Kanawha River Basin is continental, with four distinct seasons and marked temperature contrast between summer and winter (Messinger and Hughes, 2000). Temperature decreases with increasing altitude, but is consistent among the physiographic provinces. Mean annual air temperature in the basin ranges from 48°F at several locations to 55°F near Charleston, W.Va. Precipitation in the Kanawha River Basin is strongly affected by orographic lifting, both locally and regionally. The maximum precipitation in the basin is greater than 60 in./yr both in the Allegheny Highlands and in the southern Blue Ridge. The minimum precipitation in the basin, about 36 in./yr, is in the Valley and Ridge and in the Greenbrier Valley, in a regional rain shadow.

Streamflow in the basin is most seasonally variable in the western Appalachian Plateaus and least seasonally variable in the Blue Ridge (Messinger and Hughes, 2000). Flows are greatest in February and March, and least in September and October. Seasonal distribution of precipitation is different, with maximum precipitation in May-July and minimum precipitation in November-January; flows are strongly affected by evapotranspiration during April-October.

Streams in the Blue Ridge follow a dendritic drainage pattern and have an extremely high gradient. Many mountain streams are cold and support (or formerly supported) brook trout populations, but the larger streams are warm. Streamwater is typically dilute (less than 200 mg/L dissolved solids) and neutral to slightly acidic. Streams of the Valley and Ridge Province follow a trellised drainage pattern. Bedrock in the valleys is typically shale and limestone, and waters in Valley and Ridge streams are generally neutral to slightly alkaline (pH = 7.0-8.0) and contain more dissolved solids (200-350 mg/L) than do streams in the Blue Ridge Province.

Streams throughout the Appalachian Plateaus follow a dendritic drainage pattern. Streams in the Allegheny Highlands have an extremely high gradient. Many of them are cold, and even some streams draining areas larger than 100 mi^2 support trout populations. Bedrock in the Allegheny Highlands is generally inert, insoluble sandstone and shale. Streamwater is typically very dilute (30-100 mg/L dissolved solids) and poorly buffered, and some streams have been degraded by acidic precipitation.

Streams in the rest of the Appalachian Plateaus typically have high to moderate gradients. Some streams in the western Appalachian Plateaus are relatively flat and meandering, with long pools broken occasionally by short riffles, in contrast to the high-gradient streams with cascades and highly turbulent flow typical of most of the basin. The Greenbrier River and its eastern tributaries are underlain by limestone; their waters are neutral to mildly alkaline (pH = 7.0-8.0), well-buffered, and moderate in dissolved solids (150-200 mg/L). Bedrock in the western part of the Appalachian Plateaus is predominantly sandstone, shale, and coal, with interbedded limestone. The shale typically is more soluble than the sandstone, and relative amounts of shale increase in a gradient from south to north.

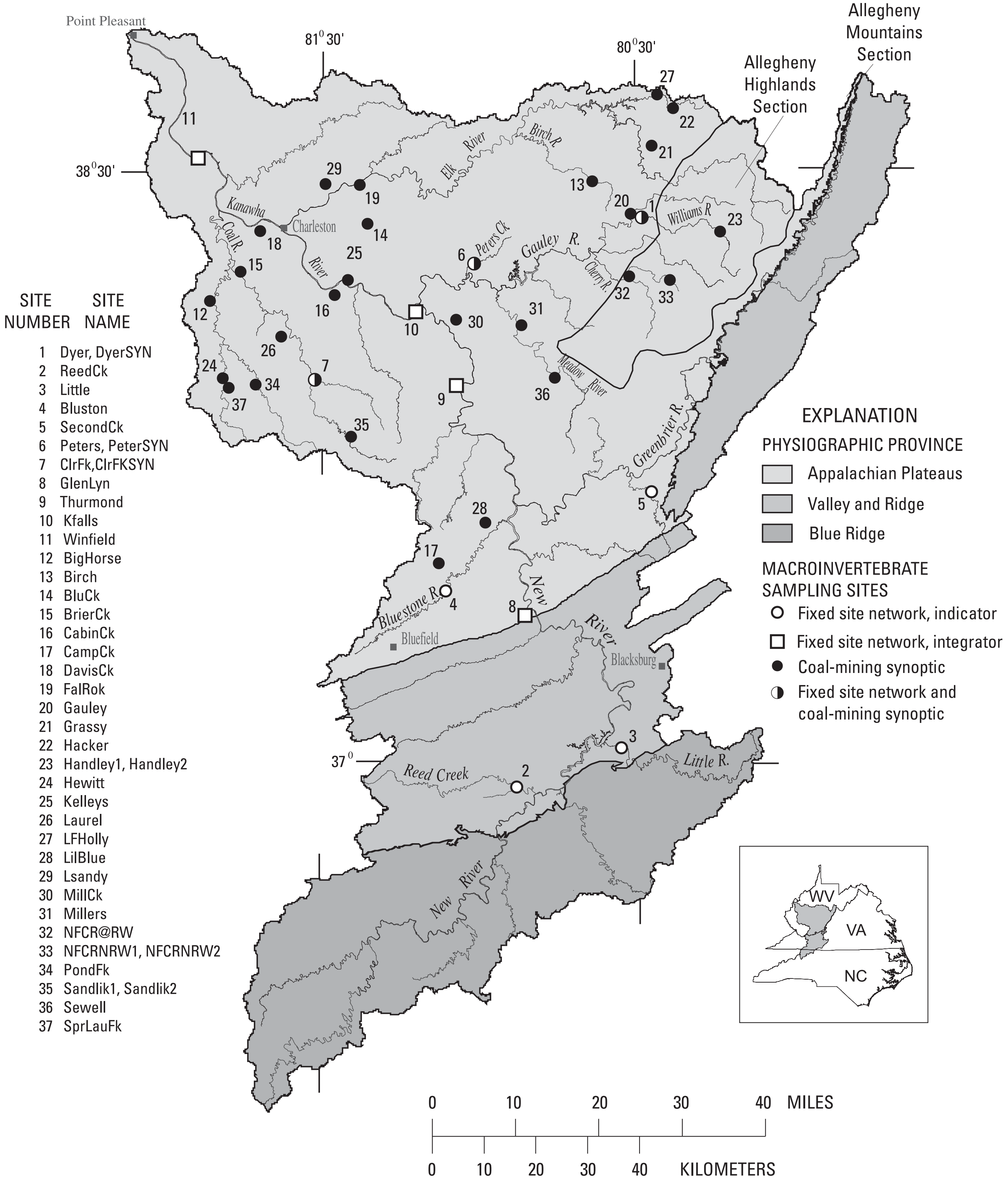
Streamwater in the western part of the Appalachian Plateaus contains more dissolved solids than any other part of the basin, with typical dissolved-solids concentrations of 500 mg/L in the Coal River and its tributaries, the downstream tributaries of the Elk River, and many minor tributaries of the Kanawha River. Most streamwater in this part of the basin is mildly alkaline and well-buffered. Streams throughout the basin are typically low in nutrients, although the Valley and Ridge and western Appalachian Plateaus contain more nutrients and are generally more productive than are streams in the Blue Ridge and the Allegheny Highlands.

The basin is mostly forest (81 per cent) with a substantial amount of agricultural land (16 percent) (Multi-Resolution Land Characteristics Interagency Consortium, 1997). Forest types vary substantially with aspect because of local orographic effects, but in general are Mixed Mesophytic in the western Appalachian Plateaus, Northern Hardwood and Northern Evergreen in the Allegheny Highlands, Oak-Pine in the Valley and Ridge, and Northern Hardwoods and Appalachian Oak in the Blue Ridge (Messinger and Hughes, 2000). The entire basin was logged by about 1920 (Clarkson, 1964). No old-growth forest larger than a few acres remains anywhere in the basin; therefore, no pristine reference sites are available for stream ecology studies.

The population distribution in the basin is rural (Messinger and Hughes, 2000). Most people live in towns and cities of less than 10,000 people (U.S. Census Bureau, 1991). In 1990, about 870,000 people lived in the basin, of whom about 25 percent lived in the Charleston, W. Va., metropolitan area. Blacksburg, Va., (34,000) is the only other city in the basin with a population greater than 20,000. Population density in most of the basin is less than 130 persons/mi^2.

Major industries in the basin include coal mining and chemical manufacturing in West Virginia, timbering throughout most of the basin, and pasture agriculture in Virginia, North Carolina, and parts of West Virginia (Messinger and Hughes, 2000). The Kanawha River Basin is the source of about seven percent of the coal mined in the United States, mostly from a band of Pennsylvanian-age rocks in West Virginia running from Logan and Boone Counties to Randolph County. Most of the coal mined in the basin is low-sulfur (<1.5 percent sulfur), and is burned to generate electricity. Acid mine drainage is generally not prevalent in the Kanawha River Basin.

Coal production in the Kanawha River Basin has increased significantly since the Clean Air Act of 1990 mandated reductions in sulfate emissions from coal-burning facilities, although previous increases in equipment efficiency had already led to increased coal production from surface mines. Mountaintop removal coal mining, a practice in which an entire ridge top is removed to uncover thin, low-sulfur coal seams, and the overburden is placed in nearby valleys and streams (valley fills), has become increasingly prevalent. Major effects of coal mining on streams include addition of sulfate, aluminum, iron, and manganese to water, and an increase in stream sedimentation. Base flow (streamflow sustained by ground-water discharge) is increased downstream from valley fills (U.S. Geological Survey, Charleston, W.Va., unpub. data, 2000), but subsidence from underground mining beneath valley floors can dewater aquifers and streams (Hobba, 1981)



SITE NUMBER	SITE NAME
1	Dyer, DyerSYN
2	ReedCk
3	Little
4	Bluston
5	SecondCk
6	Peters, PeterSYN
7	ClrFk,ClrFKSYN
8	GlenLyn
9	Thurmond
10	Kfalls
11	Winfield
12	BigHorse
13	Birch
14	BluCk
15	BrierCk
16	CabinCk
17	CampCk
18	DavisCk
19	FalRok
20	Gauley
21	Grassy
22	Hacker
23	Handley1, Handley2
24	Hewitt
25	Kelleys
26	Laurel
27	LFHolly
28	LilBlue
29	Lsandy
30	MillCk
31	Millers
32	NFCR@RW
33	NFCRNRW1, NFCRNRW2
34	PondFk
35	Sandlik1, Sandlik2
36	Sewell
37	SprLauFk

EXPLANATION

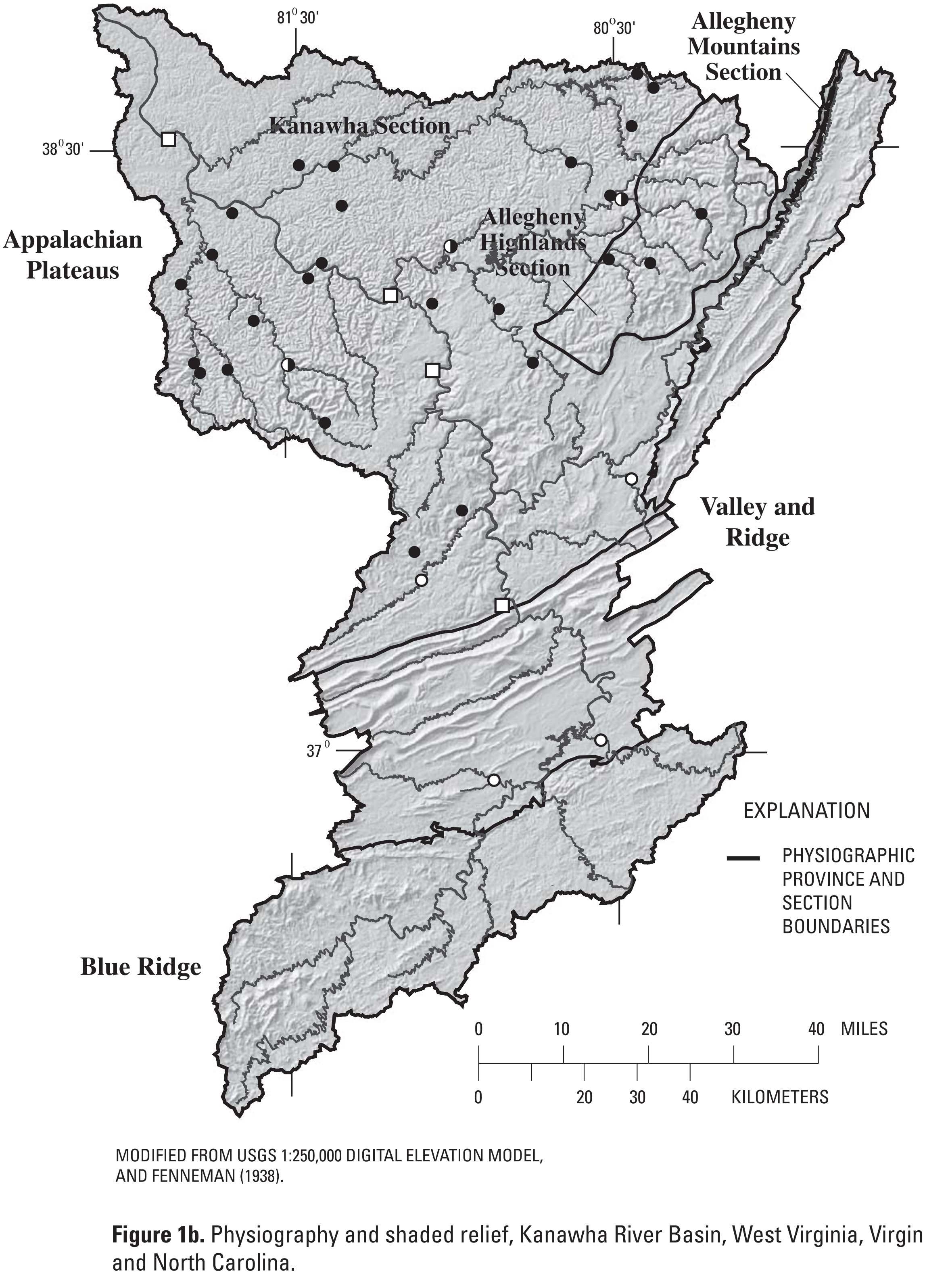
PHYSIOGRAPHIC PROVINCE

- Appalachian Plateaus
- Valley and Ridge
- Blue Ridge

MACROINVERTEBRATE SAMPLING SITES

- ○ Fixed site network, indicator
- ☐ Fixed site network, integrator
- ● Coal-mining synoptic
- ◑ Fixed site network and coal-mining synoptic

Figure 1a. Location of benthic invertebrate sampling sites and physiographic provinces, Kanawha River Basin, West Virginia, Virginia and North Carolina, 1997-1998. Full site names are provided in Tables 1 and 2.



MODIFIED FROM USGS 1:250,000 DIGITAL ELEVATION MODEL, AND FENNEMAN (1938).

Figure 1b. Physiography and shaded relief, Kanawha River Basin, West Virginia, Virginia, and North Carolina.

Purpose and Scope

This report assesses the effect of selected environmental factors on benthic invertebrate communities in the Kanawha River Basin. Environmental factors investigated include land use/land cover, streamwater chemistry, streambed-sediment chemistry and habitat characteristics. We investigated the effect of several land uses important in the Basin. The report includes a comparison of community characteristics of four main stem and seven tributary sites that differ in land use and physiography throughout the Virginia and West Virginia portions of the study area. Sites were sampled in late spring and early summer of 1997 and 1998. The report also evaluates the effects of coal mining by comparing community characteristics of 29 sites in the Appalachian Plateaus. Benthic invertebrate, streamwater chemistry, and streambed sediment samples, as well as habitat data, from these 29 sites were collected, and the relations among these factors and land use were analyzed. Sites sampled varied in coal-mining intensity, mining practice, and other land-use characteristics.

Acknowledgments

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STUDY DESIGN

The study consists of two overlapping components with different objectives. Samples were collected at 37 sites throughout the Kanawha River Basin (fig. 1). Four “integrator” sites on the main stem of the Kanawha and New Rivers reflect multiple geologic and land-use settings in drainage basins larger than 3,700 mi^2. Seven “indicator” sites in basins of 40 to 300 mi^2 represent relatively homogeneous settings throughout the study area. Twenty-nine “synoptic” sites, including three sites from the fixed-site network, in West Virginia basins of 8.79 to 128 mi^2 represent a gradient of coal-mining intensity ranging from unmined to heavily mined.

Fixed-Site Network Design and Sampling

The fixed-site network consists of the four integrator sites and the seven indicator sites (table 1). Indicator sites represent important land-use patterns in the Kanawha River Basin, namely coal mining and agriculture in the Appalachian Plateaus, Valley and Ridge, and Blue Ridge Provinces (Fenneman, 1938), and a highly distributed rural residential setting. At all sites, we selected a sampling reach so as to be representative of the stream segment, consisting of one repetition of two consecutive geomorphic channel units such as riffles, runs, or pools (Cuffney and others, 1993). Field teams collected benthic invertebrate samples, measured reach-level habitat characteristics, and collected streambed-sediment samples at least once at each of the sites. At three sites, Williams River at Dyer, W.Va., Reed Creek at Grahams Forge, Va., and Clear Fork at Whitesville, W. Va., three reaches were selected where we sampled invertebrates and measured habitat characteristics. At these three sites, we also collected invertebrates from one of the reaches for two consecutive years.

Invertebrate samples were collected at all 11 fixed sites between May 5 and July 3, 1997; samples were collected from the multiple reach sites, including the reach sampled the previous year. This group of samples is referred to as May-June samples. Continuous discharge and temperature were measured at all sites. Streamwater was sampled monthly and additionally during high flow conditions at all sites. Streamflow, streamwater chemistry, and streambed-sediment data can be found in Ward and others (1998 and 1999); continuous water temperature data can be found in Ward and others (2000).

Benthic invertebrate samples were collected from the habitat expected to support the richest invertebrate community (most taxa) -- typically riffles with gravel, cobble, and boulder substrate. Samples were collected by disturbing a 0.25 m^2 area of riffle substrate immediately upstream of a Slack sampler (425 micrometer mesh) (Cuffney and others, 1993) and allowing the dislodged material to drift into the sampler. We also inspected cobble-sized and larger substratum for attached organisms, removing these with brushes and forceps. The Kanawha River at Winfield

Table 1. Station descriptions and land-use data for the basic fixed-site network sampled in the Kanawha River Basin

[mi, mile; MRLC, Multiple Resolution Land Characteristics data; superscript numbers correspond with site number given on figure 1; Transitional Areas, areas currently undergoing changes in land use, such as construction areas]

Station Name and Station Number (Abbreviated site name used in figures)	Drainage Area (mi^2)	Station Heading	Percentage of Basin Area in MRLC Land-Use Classes				
			Total Forest	Total agriculture	Residential, Commercial, Industrial	Quarries, Strip Mines, Gravel Pits	Transitiona l areas
Williams River at Dyer, W. Va.[1] 03186500 (Dyer)	128	Indicator: reference condition in Appalachian Plateaus Physiographic Province	96.8	2.2	0.03	0	0.61
Reed Creek at Grahams Forge, Va.[2] 03167000 (Reed)	247	Indicator: agriculture in Valley and Ridge Physiographic Province	53.0	43.6	2.7	0.04	0.23
Little River at Graysontown, Va[3] 03170000 (Little)	300	Indicator: agriculture in Blue Ridge Physiographic Province	62.8	36.4	0.18	0	0.24
Bluestone River near Spanishburg, W. Va.[4] 03178000 (Bluston)	199	Indicator: rural residential in both Valley and Ridge and Applachian Plateaus Physiographic Province	80.7	14.3	3.1	0.52	0.86
Second Creek near Second Creek, W. Va.[5] 03183000 (Second)	80.8	Indicator: agriculture in carbonate portion of Appalachian Plateaus Physiographic Province	72.0	25.3	0.13	0.00	2.08
Peters Creek near Lockwood, W. Va.[6] 03191500 (Peters)	40.2	Indicator: coal mining in Appalachian Plateaus Physiographic Province	88.2	7.7	0.69	2.00	1.15
Clear Fork at Whitesville W. Va.[7] 03198350 (ClrFk)	62.8	Indicator: coal mining in Appalachian Plateaus Physiographic Province	94.0	1.9	0.42	2.3	1.17
New River at Glen Lyn, Va.[8] 03176500 (GlenLyn)	3,768	Integrator of Blue Ridge and Valley and Ridge Physiographic Provinces	67.8	29.5	1.66	0.02	0.22
New River at Thurmond, W. Va.[9] 03185400 (Thurmond)	6,687	Integrator, below the Greenbrier River, the largest unsampled tributary	73.1	24.0	1.43	0.06	0.51
Kanawha River at Kanawha Falls, W. Va.[10] 03193000 (KFalls)	8,371	Integrator, below major tributary, change in stream gradient, above head of navigation and industrial-urban center	76.3	20.5	1.3	0.33	0.59
Kanawha River at Winfield, W. Va.[11] 03201300 (Winfield)	11,809	Integrator, in navigable reach, below all urban and industrial land uses	80.7	15.8	1.53	0.51	0.57

Table 2. Environmental setting data and key to short names used in illustrations for coal-mining synoptic sites sampled in the Kanawha River Basin

[PRE, mined before 1980 and not since; MIXED, (in time of mining column), mined both before and after 1980; DEEP, mined only using deep mining techniques; MIXED (in mining method column), mined using both deep- and surface-mining techniques; MRLC, Multi-resolution land characteristics data; Trans/Comm/Ind, mixed transportation, commercial and industrial land use; mi^2, square mile; ft, feet; WMA, Wildlife Management Area; superscript numbers correspond with site numbers given in figure one]

		Mining Setting				**MRLC land-use/land-cover data (Percent of basin area)**					
Station Name	**Sample Name**	**Time of Mining**	**Mining Method**	**Drainage Area (mi^2)**	**Elevation (ft)**	**Residential**	**Mining**	**Trans/ Comm/ Ind**	**Forest**	**Agriculture**	**Coal Production (thousand tons/mi^2)**
Big Horse Creek at Altman, W. Va.[12]	BigHorse	MIXED	MIXED	28.4	664	0.24	3.33	0.01	93.5	2.90	20
Birch River at Boggs, W. Va.[13]	Birch	MIXED	MIXED	16.3	1,454	0.02	2.46	0.11	91.8	5.33	8
Blue Creek at Sanderson, W. Va.[14]	BluCk	MIXED	MIXED	50.1	711	0.16	0	0.17	98.6	0.93	207
Brier Creek at Brounland, W. Va.[15]	BrierCk	PRE	MIXED	15.8	714	0.34	0	0.12	98.1	1.39	0
Cabin Creek at Dry Branch, W. Va.[16]	CabinCk	MIXED	MIXED	70.8	620	0.93	2.80	0.41	94.1	1.52	320
Camp Creek near Camp Creek, W. V.a[17]	CampCk	PRE	DEEP	18.8	2,013	0.08	0	0.17	92.6	6.93	0
Clear Fork at Whitesville, W. V.a[7]	ClrFkSYN	MIXED	MIXED	63.2	1,190	0.26	2.27	1.17	94.0	1.94	344
Davis Creek at Davis Creek, W. Va.[18]	DavisCk	PRE	MIXED	35.8	570	4.93	0.18	0.09	91.5	2.86	0
Williams River at Dyer, W. Va.[1]	DyerSYN	PRE	MIXED	128	2,195	0.01	0	0.32	96.8	2.46	0
Falling Rock Creek at Falling Rock, W. Va[19]	FalRok	PRE	MIXED	24.6	608	0.01	0	0.05	97.9	1.95	0

Table 2. Environmental setting data and key to short names used in illustrations for coal-mining synoptic sites sampled in the Kanawha River Basin —Continued

[PRE, mined before 1980 and not since; MIXED, (in time of mining column), mined both before and after 1980; DEEP, mined only using deep mining techniques; MIXED (in mining method column), mined using both deep- and surface-mining techniques; MRLC, Multi-resolution land characteristics data; Trans/Comm/Ind, mixed transportation, commercial and industrial land use; mi^2, square mile; ft, feet; WMA, Wildlife Management Area; superscript numbers correspond with site numbers given in figure one]

		Mining Setting				MRLC land-use/land-cover data (Percent of basin area)					
Station Name	**Sample Name**	**Time of Mining**	**Mining Method**	**Drainage Area (mi^2)**	**Elevation (ft)**	**Residential**	**Mining**	**Trans/ Comm/ Ind**	**Forest**	**Agriculture**	**Coal Production (thousand tons/mi^2)**
Gauley River atWilliams River, W. Va.^{20}	Gauley	MIXED	MIXED	75.3	2,168	0.17	0.34	0.02	96.9	2.30	54
Grassy Creek at Diana, W. Va.^{21}	Grassy	MIXED	MIXED	19.4	1,327	0.16	0.60	0.01	96.9	2.29	9
Laurel Fork at Hacker Valley, W. Va.^{22}	Hacker	UNMINED	UNMINED	11.5	1,492	0.01	0	0.02	99.0	0.82	0
Williams River near Handley WMA, W. Va.^{23}	Handley1 Handley2	PRE	DEEP	51.6	2,938	0.02	0	0.66	93.7	5.12	0
Hewitt Creek at Jeffrey, W. Va.^{24}	Hewitt	MIXED	MIXED	18.9	778	0.53	0.44	0.05	97.1	1.88	8
Kellys Creek at Cedar Grove, W. Va.^{25}	Kellys	MIXED	MIXED	24.1	598	0.63	2.31	0.53	92.8	3.59	957
Laurel Creek at Hopkins Fork, W. Va.^{26}	Laurel	MIXED	MIXED	41.3	705	0.09	2.44	0.03	95.8	1.54	690
Left Fork Holly River near Replete, W. Va.^{27}	LFHolly	PRE	DEEP	46.5	837	0.06	0.10	0.03	97.7	1.98	0
Little Bluestone River near Jumping Branch, W. Va.^{28}	LilBlue	PRE	MIXED	26.4	1,601	0.15	0.06	0.02	80.8	18.50	0
Little Sandy Creek at Wills, W. Va.^{29}	Lsandy	UNMINED	UNMINED	28.2	624	0.10	0	0.02	95.7	4.21	0

Table 2. Environmental setting data and key to short names used in illustrations for coal-mining synoptic sites sampled in the Kanawha River Basin —Continued

[PRE, mined before 1980 and not since; MIXED, (in time of mining column), mined both before and after 1980; DEEP, mined only using deep mining techniques; MIXED (in mining method column), mined using both deep- and surface-mining techniques; MRLC, Multi-resolution land characteristics data; Trans/Comm/Ind, mixed transportation, commercial and industrial land use; mi^2, square mile; ft, feet; WMA, Wildlife Management Area; superscript numbers correspond with site numbers given in figure one]

		Mining Setting				**MRLC land-use/land-cover data (Percent of basin area)**					
Station Name	**Sample Name**	**Time of Mining**	**Mining Method**	**Drainage Area (mi^2)**	**Elevation (ft)**	**Residential**	**Mining**	**Trans/ Comm/ Ind**	**Forest**	**Agriculture**	**Coal Production (thousand tons/mi^2)**
Mill Creek near Hopewell, W. Va.[30]	MillCk	UNMINED	UNMINED	22.41	1,308	1.12	0	0.30	88.7	9.63	0
Miller Creek at Nallen, W. Va.[31]	Millers	UNMINED	UNMINED	8.79	1,904	0.0	1.68	1.00	94.8	2.50	0
North Fork Cherry River at Richwood, W. Va.[32]	NFCR@RW	MIXED	MIXED	36.4	2,223	0.04	0.01	0.03	98.3	1.15	1.4
North Fork Cherry River near Richwood, W. Va.[33]	NFCRNRW 1 NFCRNRW 2	PRE	DEEP	11.8	3,211	0.01	0.02	0.02	99.3	0.35	0
Peters Creek near Lockwood, W. Va.[6]	PeterSYN	MIXED	MIXED	40.2	1,069	0.22	2.19	0.43	88.1	8.73	746
Pond Fork at Bob White, W. Va.[34]	PondFk	MIXED	MIXED	58.3	844	0.69	4.22	0	93.1	1.86	2,026
Sandlick Creek near Arnett, W. Va.[35]	Sandlik1 Sandlik2	MIXED	MIXED	19.9	1,632	0.16	0.73	0	90.7	8.14	406
Sewell Creek at East Rainelle, W. Va.[36]	Sewell	MIXED	MIXED	40.1	2,400	1.08	0.36	1.66	85.9	10.25	3.5
Spruce Laurel Fork at Clothier, W. Va.[37]	SprLauFk	MIXED	MIXED	31.8	810	0.14	2.54	0	96.0	1.20	391

was the only site where we deviated from this procedure and sampled channel-margin shelves with a petite PONAR dredge because of the absence of both riffles and coarse-grained substrates. At each sampling point, we measured depth and current velocity, recorded dominant and codominant substrate size by Wentworth size class (Wentworth, 1922), and estimated substrate embeddedness. Five to seven such samples were combined as a composite sample for the reach. Details of sampling methods can be found in Cuffney and others (1993); benthic invertebrate-community data can be found in Ward and others (1999).

Coal-Mining Synoptic Survey Design and Sampling

A second network of sites was established to investigate the interactions of invertebrate communities and environmental conditions in the West Virginia coal-mining region of the Kanawha River Basin. Secondarily, we used this synoptic as a measure of the representativeness of our fixed mining and reference sites. Sites represent a range of conditions from apparently unmined, to mined before enactment of the Surface Mining Control and Reclamation Act of 1977, to currently being mined at various levels of intensity (table 2). These sites, draining areas ranging from 8.79 to 128 square miles, included three sites from the fixed-site network —Williams River at Dyer, Peters Creek near Lockwood, and Clear Fork at Whitesville.

During July and August of 1998, we collected streamwater-chemistry samples, streambed-sediment samples, and benthic invertebrate samples; we also measured streamflow and physical habitat characteristics. We established sampling reaches at each site using the same criteria as for the fixed sites —one repetition of two consecutive geomorphic channel units such as riffles, runs or pools. The USGS’s National Water-Quality Laboratory (NWQL) analyzed streamwater samples for major ion concentrations and total and dissolved metal concentrations (table 3). Composite samples of the top 2-3 cm of stream-bottom material (Shelton and Capel, 1993) were analyzed by the NWQL for metal and trace elements concentrations (table 4). We collected invertebrate samples following the procedures described for invertebrate samples in the section on fixed-site network design. Replicate invertebrate samples from adjacent stream reaches were collected at three sites,—Williams River at Handley Wildlife Management Area, North Fork of the Cherry River near Richwood, and Sandlick Creek near Arnett. This group of samples is referred to as July-August, or synoptic samples.

Physical habitat was characterized by measuring wetted channel width, bankfull height, and bankfull width at three transects corresponding to the two riffles and the intervening pool in a reach. At each transect, we also measured depth and current velocity at three points, and identified the dominant and subdominant substrate class at these three points. We also characterized particle-size distribution by measuring the intermediate axis of 100 streambed particles equally distributed among the three transects. Streamwater chemistry and benthic invertebrate-community data can be found in Ward and others, 1999; streambed-sediment-chemistry data can be found in Ward and others, 2000.

Table 3. Chemical and physical characteristics of streamwater measured as part of the coal-mining synoptic survey of the Kanawha River Basin

[μS/cm, microSiemens per centimeter; mg, milligram; L, liter; μg, microgram]

Characteristic	Units
Instantaneous Discharge	Cubic Feet per Second
Water Temperature	Degrees Celsius
Specific Conductance	μS/cm at 25 C^o
Dissolved Oxygen	mg/L
pH	Standard Units
Dissolved Carbon Dioxide	mg/L as CO_2
Total Acidity	mg/L as $CaCO_3$
Dissolved Alkalinity	mg/L as $CaCO_3$
Dissolved Carbonate	mg/L as CO_3
Dissolved Bicarbonate	mg/L as HCO_3
Total Hardness	mg/L as CaO_3
Dissolved Noncarbonate Hardness	mg/L as $CaCO_3$
Dissolved Calcium	mg/L as Ca
Dissolved Magnesium	mg/L as Mg
Dissolved Sodium	mg/L as Na
Dissolved Potassium	mg/L as K
Dissolved Chloride	mg/L as Cl
Dissolved Sulfate	mg/L as SO_4
Dissolved Fluoride	mg/L as F
Dissolved Silica	mg/L as SiO_2
Total Iron	μg/L as Fe
Dissolved Iron	μg/L as Fe
Total Manganese	μg/L as Mn
Dissolved Manganese	μg/L as Mn
Total Aluminum	μg/L as Al
Dissolved Aluminum	μg/L as Al

Table 4. Chemical constituents analyzed in streambed-sediment samples collected as part of the coal-mining synoptic survey of the Kanawha River Basin

[µm, micrometer; µg, microgram; g, gram; All samples wet-seived at 63 µm]

Constituent	Units
Aluminum	percent
Antimony	µg/g
Arsenic	µg/g
Barium	µg/g
Beryllium	µg/g
Bismuth	µg/g
Cadmium	µg/g
Calcium	percent
Inorganic Carbon	percent
Organic Carbon	percent
Cerium	µg/g
Chromium	µg/g
Cobalt	µg/g
Copper	µg/g
Europium	µg/g
Gallium	µg/g
Gold	µg/g
Holmium	µg/g
Iron	percent
Lanthanum	µg/g
Lead	µg/g
Lithium	µg/g
Magnesium	percent
Manganese	µg/g
Mercury	µg/g
Molybdenum	µg/g
Neodymium	µg/g
Nickel	µg/g
Niobium	µg/g
Phosphorus	percent
Potassium	percent
Scandium	µg/g
Selenium	µg/g
Silver	µg/g
Sodium	percent
Strontium	µg/g
Sulfur	percent
Tantalum	µg/g
Thorium	µg/g
Tin	µg/g
Titanium	percent
Uranium	µg/g
Vanadium	µg/g
Ytterbium	µg/g
Yttrium	µg/g
Zinc	µg/g

Invertebrate Sample Analysis

The Biological Group of the USGS’s National Water-Quality Laboratory analyzed all invertebrate samples. Subsamples were taken from the samples and up to 500 organisms from the subsample were identified and counted (Moulton and others, 2000). Results were adjusted to total sample abundances, which were divided by area sampled to derive the number of individuals in taxa per m^2 (taxa density).

Land-Use Data

Relations among invertebrate communities and land-use characteristics, such as land-cover data and coal production, were analyzed. We used the Multi-Resolution Land Characteristics (MRLC) data set for all land-cover/

land-use data in our analysis. The MRLC dataset was based primarily on 1992 LANDSAT thematic mapper imagery, but incorporates LANDSAT data from 1986 to 1994 (Multi-Resolution Land Characteristics Interagency Consortium, 1997). We derived coal production data from production figures reported by companies to the Department of Energy's Energy Information Administration. For the period of 1980-1995 (the most recent year for which data were available), we assembled production data and matched it with location coordinates for mining permits (Emil Attanasi, USGS, written comm., 1997). If the associated location fell within a basin's drainage area, we assigned the production value to that basin. The assignment of coal production to a single point introduces error, however, because mining takes place over wide areas, not just at the coordinates indicated on the permit. This situation is true of surface mines, which can cover thousands of hectares and span drainage divides, and deep mines, which can also be areally extensive and may result in interbasin water transfers.

Seasonal Variability in the Data Set

Initially, we intended to use samples collected as part of the coal-mining synoptic survey to supplement samples from the fixed-site network. We collected samples, however, during two distinct seasons. Fixed sites were sampled primarily in late spring (May-June), and synoptic sites were sampled in mid summer (July-August). Before combining these data sets for analysis, we examined the possibility of a seasonal effect on community composition because of sequential changes in taxa abundance as temperatures change and different species mature and emerge. These effects arise as species composition shifts in response to changing stream environments as seasons progress. We compared samples collected from the same reach during different seasons and during different years, and in different reaches of the same stream segment during the same year and season. Samples collected at the same site in different seasons of the same year were less similar than samples collected in the same reach in the same season, but in different years, indicating that data from different seasons were not directly comparable and could not be combined. The comparisons were made using hierarchical classification.

The TWINSPAN program (Two-Way INdicator SPecies ANalysis, Hill; 1979) was used to classify sampled sites on the basis of invertebrate-community composition. The basic approach of TWINSPAN is to classify samples in a divisive hierarchy, then use this classification to identify differential species, or species that

show a clear ecological preference. TWINSPAN sequentially divides a set of samples into groups, known as clades, based on the similarity between the taxa and their abundances in each sample. Each clade can be distinguished from the adjacent clade by certain characteristic taxa. In Figure 2, for example, the clades separated in the first division of samples differed in the presence of the chironomid midges *Cricotopus* spp. and *Orthocladius* spp. in one clade versus the presence of several taxa such as *Dolophilodes* spp., *Leuctra* spp., and *Acerpenna* spp. in the other clade. It is assumed that the preference of species for particular sites is a reflection of both that species' environmental requirements and the conditions in the stream at the time the sample was collected.

In classification, as well as in ordination, data must commonly be edited and censored to reduce confusing taxonomical information, such as ambiguous taxa, and the inflated influence of rare species. Invertebrate specimens were identified to the lowest taxon practical, which resulted in some cases in ambiguous classifications within a sample – for example, some individuals of a given species identified at the generic level and other individuals in the same sample identified at the lower species level, possibly because of difficulty identifying immature or damaged specimens. To increase the consistency of data both within and among samples, we combined data at a generic level by adding species-level data to the counts for the parent genus. Where identifications were made at the family level, we distributed these counts proportionally among the daughter genera present in the sample. To reduce the effects of rare species, we censored taxa comprising less than 0.04 percent of the total abundance of the data set. We transformed all edited and censored density data to relative abundance. Before classification, relative-abundance data were octave transformed, a base 2 logarithmic transformation of percentage data resulting in values of 0-9 (Gauch, 1977).

TWINSPAN classification of all indicator-site samples indicated a seasonal effect in the data (fig. 2). The samples collected in May-June differed significantly enough from the July-August samples that these groups are treated separately throughout this report. When all 48 indicator-site samples were considered together, six levels of division placed one to five samples in each final clade. For all three sites where samples were collected both during May-June and July-August, the later sample divided from the earlier ones

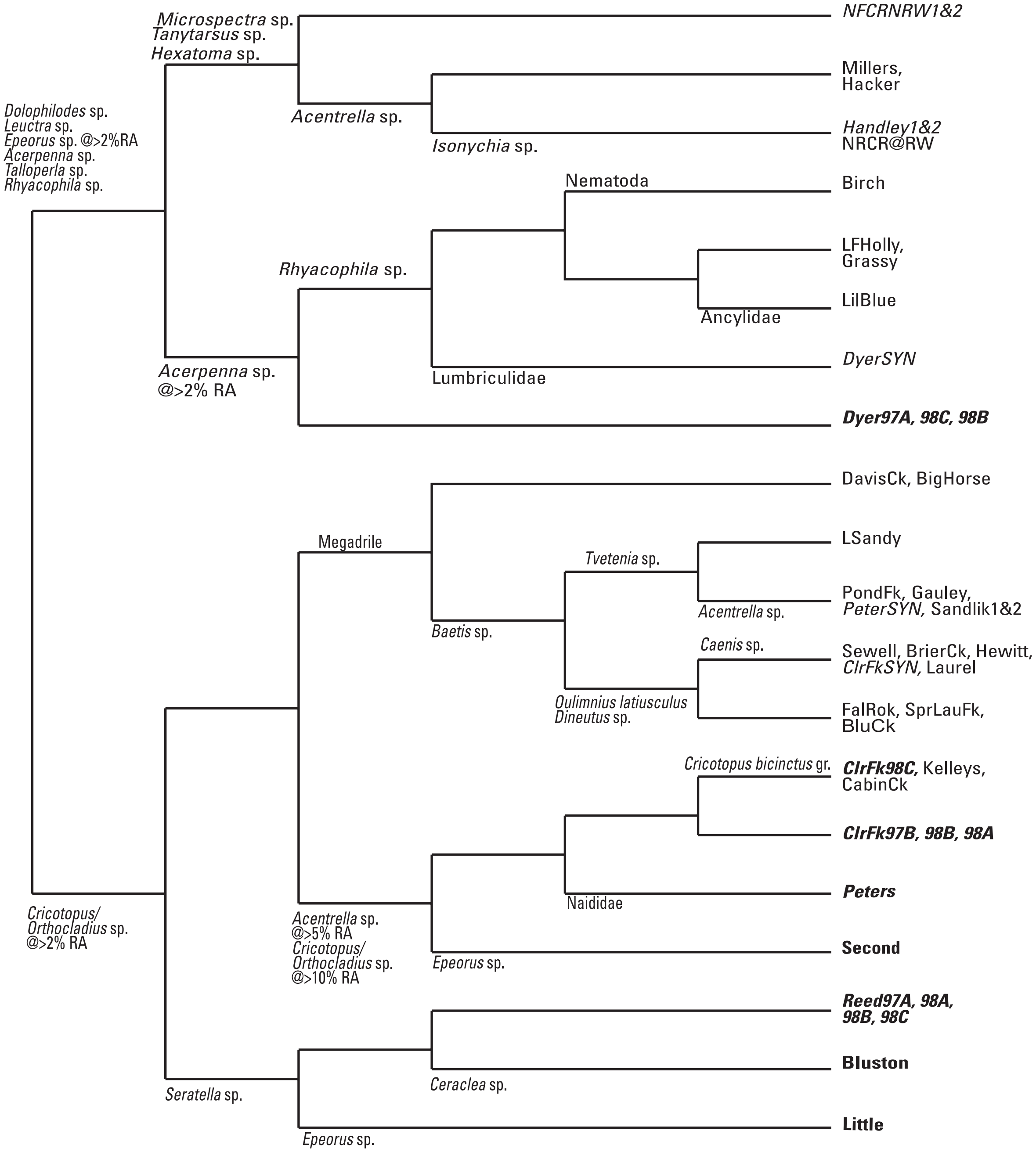

Figure 2. Hierarchical classification of all indicator site samples in the Kanawha River Basin, showing seasonal variation in multiple samples from the same site. (May-June samples are in bold; July-August samples in plain text. @>10% RA, at greater than 10-percent relative abundance. Short names of sites are defined in tables 1 and 2. Sites with multiple samples shown in italics.)

at the third level. In contrast, for five sites where 14 samples were collected within one season, only one separated from its replicates, and then only at the final division. These seasonal effects are strong enough to obscure other factors in a combined analysis. It would be inappropriate therefore to combine data from samples collected in two different collecting seasons. In accordance with these findings, we elected to treat these two data sets, one from the fixed-site network and one from the coal-mining synoptic, as separate and to analyze them individually.

BENTHIC INVERTEBRATE COMMUNITIES

Invertebrate communities can be described in several ways —by species composition, habitat use, food-resource use, and mathematical summaries of other community attributes or metrics. We described samples from our two data sets on the basis of the community attributes listed in table 5. Where appropriate, we compared attribute values to reference or best-attained conditions in each data set.

Table 5. Biological metrics used in comparisons of macroinvertebrate samples from sites sampled in the Kanawha River Basin

[Metric definitions and expected responses from Barbour and others, 1999, and Bode and others, 1996]

Metric	Definition	Expected response to increasing environmental impairment
EPT	Number of Ephemeroptera, Plecoptera, and Trichoptera taxa	Decrease
EP	Number of Ephemeroptera and Plecoptera taxa	Decrease
EPT Abundance	Relative abundance of Ephemeroptera, Plecoptera, and Trichoptera taxa	Decrease
Chironomidae Abundance	Relative abundance of Chironomidae	Increase
EPT Abundance: Chironomidae Abundance	Ratio of EPT Abundance to Chironomidae Abundance	Decrease
Percent Dominant Taxa	Relative abundance of the single most abundant taxon	Increase
Percent 2 Dominant Taxa	Relative abundance of the two most abundant taxa	Increase
Taxa Richness	Number of taxa	Decrease
Modified Hilsenhoff Biotic Index	Summary of community tolerance to pollution	Increase
Proportion of Shredders	Relative abundance of taxa belonging to “shredder” feeding group	Decrease
Proportion of Collector-Filterers	Relative abundance of taxa belonging to “Collector-Filterer” feeding group	Variable
Proportion of Collector-Gatherers	Relative abundance of taxa belonging to “Collector-Gatherer” feeding group	Variable
Proportion of Scrapers	Relative abundance of taxa belonging to “Scraper” feeding group	Variable
Proportion of Predators	Relative abundance of taxa belonging to “Predator” feeding group	Variable
Scrapers:Collector-Filterers	Ratio of Scrapers to Collector-Filterers	Decrease
Scrapers:Collector-Filterers and Scrapers	Ratio of Scrapers to Collector-Filterers and Scrapers	Decrease
Proportion Hydropyschidae to Trichoptera	Relative abundance of pollution tolerant caddisflies	Increase
Proportion Baetidae to Ephemeroptera	Relative abundance of pollution tolerant mayflies	Increase
Proportion Orthocladiinae to Chironomidae	Relative abundance of pollution-tolerant midges to all midges	Increase
Proportion Tanytarsini to Chironomidae	Relative abundance of pollution-intolerant midges to all midges	Decrease
Proportion Tanytarsini to Total	Relative abundance of pollution-intolerant midges to total abundance	Decrease
Proportion Chironomidae to Total	Relative abundance of midges to total abundance	Increase
Percent Model Affinity	Similarity of taxa composition to “model” reference composition of 5% Oligochaeta, 40% Ephemeroptera, 5% Plecoptera, 10% Coleoptera, 10% Trichoptera, 20% Chironomidae, and 10% other taxa	Decrease

Comparison of Samples Collected as Part of the Fixed-Site network

The fixed-site data set consists of 20 samples from a relatively disparate collection of eleven sites, representing three physiographic provinces, four ecoregions, and drainage areas ranging from less than 50 mi^2 to nearly 12,000 mi^2. Such variety makes direct comparison of sites difficult, as reference conditions were defined in only one of the physiographic provinces. Furthermore, community composition varies with stream order and drainage area (Vannote and others, 1980) and the fixed-site network spans several orders of magnitude of drainage area. Lastly, because we used a different sampling method and targeted habitat at Kanawha River at Winfield, W. Va., results for this site were not compared with the other sites. Given these caveats, however, we made comparisons to our *a priori* defined reference conditions of Williams River at Dyer, using the mean value of all four samples from this site as our benchmark. Metric values for May-June samples are shown in figures 3-5 with values for Williams River at Dyer samples first, followed by the remainder of the indicator-basin sites in downstream order, then the integrator-site samples.

Overall, metric values at Williams River at Dyer indicated communities with minimal impairment. Other sites with metric values that frequently exceeded those of the reference condition include Little River, Second Creek and some samples from Reed Creek. These three basins were similar in that agriculture represented the prevalent non-forest land cover, of which the majority is pasture and hay cultivation. Reed Creek samples were highly variable, both from reach-to-reach and from year-to-year, and generally reflected a higher level of impairment than the other agricultural sites. This fact may be due to not only the greater proportion of the basin used for agriculture but also other land uses, such as an interstate highway and the town of Wytheville, Va. Given the rather small set of sites to compare, agricultural practices in Kanawha River Basin appear to affect invertebrate communities to a lesser degree than mining affects invertebrate communities. Coal-mining indicator samples consistently reflected a greater degree of impairment than either reference or agricultural sites. Additionally, the Clear Fork samples indicated more impairment than Peters Creek, although coal production was higher in the Peters Creek basin. Metric values at integrator sites may be more indicative of the very different stream environment at these sites draining large basins than the influence of any land-use pattern.

Species-composition characteristics such as taxa richness, number of taxa belonging to certain groups, and proportional representation of specific taxa or taxa groups provided a basis for describing samples. Taxa richness -- the number of taxa present in a sample -- measures the diversity of a sample. Generally, high taxa richness is indicative of low community impairment. Taxa richness can be affected by several environmental characteristics, including stream order, trophic status, and water quality. Taxa richness was highest in the samples from Little River and the sample from Williams River at Dyer reach B, with 44 taxa in each sample (fig. 3a). Of the samples collected from riffles using a Slack sampler, the lowest taxa richness was 15 in the 1998 sample from Clear Fork, reach B. Mean taxa richness for all sites was 30. Taxa richness at Williams River at Dyer averaged 35 taxa per sample (range 23-44, standard deviation [s.d.] 9.7). The number of taxa present was generally lower in samples from integrator sites than in samples from the indicator basins. Samples from the Clear Fork coal-mining indicator site departed from this pattern, with three out of four samples from this site yielding the fewest species of all the samples. Taxa richness at Peters Creek, the other coal-mining indicator site, exceeded the reference condition mean. The high taxa richness of the Williams River at Dyer samples belie the dilute, oligotrophic nature of the Williams, because productive streams will often support more species (Allan, 1995; Dodson and others, 2000). Agricultural and rural-residential indicator sites ranged widely in taxa richness values (23 to 44), although most exceeded the reference condition mean. Low taxa richness at Reed Creek, averaging 30 genera, was a clear exception among the agricultural indicator sites.

The presence of particular taxa or taxa groups, such as Ephemeroptera (mayflies), Plecoptera (stoneflies), or Trichoptera (caddisflies), which are collectively referred to as EPT taxa, can indicate general environmental conditions. For example, a high EPT score is associated with low levels of impairment because EPT taxa are generally intolerant of pollution. These taxa, however, are not all sensitive to the same forms of environmental degradation and the presence of many different EPT taxa indicates the absence of multiple stressors or sources of degradation. The number of EPT taxa, or EPT taxa richness, followed the same general pattern as overall taxa richness, with

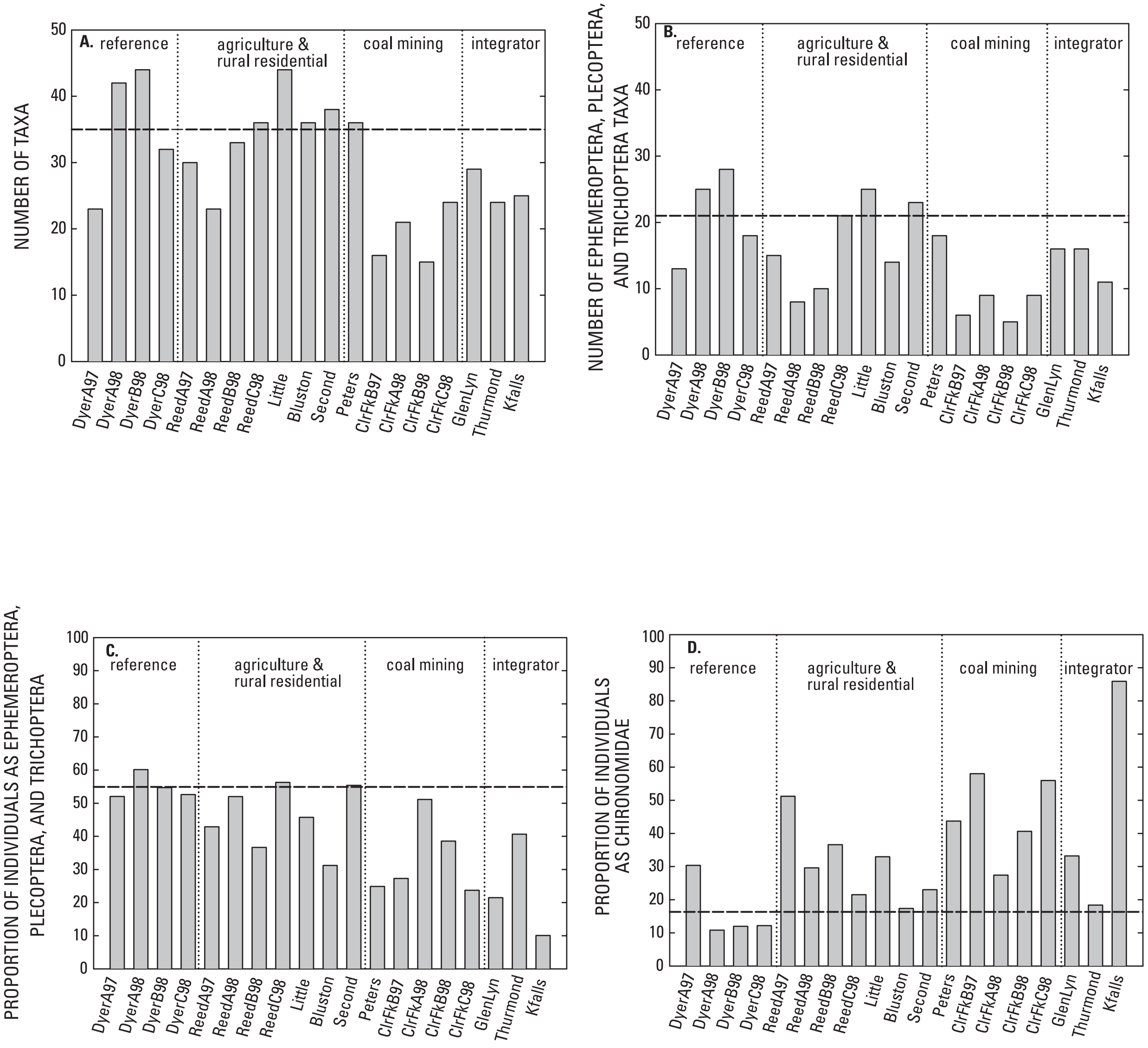

Figure 3 a-d. Community composition metric values showing (A.) taxa richness, (B.) number of Ephemeroptera, Plecoptera, and Trichoptera taxa, (C.) proportion of individuals as Ephemeroptera, Plecoptera, and Trichoptera, and (D.) proportion of individuals as Chironomidae for sites representing selected environmental settings in the Kanawha River Basin. (Dashed lines indicate the mean value for reference-condition samples from the Williams River at Dyer. Full names of sites given in tables 1 and 2).

lower values for Clear Fork and integrator site samples. EPT taxa richness was highest in reach B of the Williams River at Dyer with 28 genera present (fig. 3b). The fewest EPT taxa, five, were found in the 1998 sample from Clear Fork, reach B. Samples from the Williams River at Dyer averaged 21 EPT taxa (range 13-28, s.d. 6.8). Among the agricultural indicator sites, the Little River and Second Creek samples exceeded the reference condition mean with 25 and 23 EPT taxa, respectively. Samples from Reed Creek averaged 14 EPT taxa, but ranged from 8 to 21. The Bluestone River, the rural residential indicator site, had relatively high taxa richness but few EPT taxa. The presence of many species at this site, but few sensitive taxa, may indicate the effects of nutrient enrichment, due to the multiple sources present in the basin such as runoff from pastures and waste-water discharges, coupled with generally poor habitat. Of the samples from the two coal-mining indicator basins, the Peters Creek sample contained twice as many EPT taxa than the Clear Fork sample with the most EPT taxa.

Proportions of organisms intolerant to environmental degradation are expected to decrease with increasing degradation. The proportion of individuals belonging to EPT taxa is one measure of the representation of intolerant organisms. Proportion of EPT individuals ranged from 60 percent of the 1998 Williams River at Dyer reach A sample, to 10 percent of the sample from Kanawha River at Kanawha Falls (fig. 3c). The mean proportion of EPT individuals for Williams River at Dyer samples was 55 percent (range 52 percent-60 percent, s.d. 3.7). Representation of EPT was generally higher in samples from agricultural indicator sites than those from coal-mining indicator sites. Proportion of EPT individuals was similar for mining sites and the Bluestone River rural residential indicator site. Of the three integrator sites, values for Glen Lyn and Kanawha Falls were the lowest of the May-June samples. The sample from Thurmond, however, had relatively high representation of EPT individuals, probably because of the rocky habitat and highly aerated waters of this high-gradient section of the New River.

In contrast to the pollution-intolerant EPT taxa, the dipteran family Chironomidae (midges) contains many taxa tolerant of highly degraded conditions. The proportion of chironomid individuals in a sample is generally believed to increase with increasing community impairment, as tolerant chironomids replace more sensitive taxa when conditions degrade. Chironomidae represented 86 percent of the sample from the Kanawha River at Kanawha Falls, but only 11 percent of the sample collected in 1998 from reach A of the Williams River at Dyer (fig. 3d). The mean value for the four Williams River at Dyer samples was 16 percent (range 11-30, s.d. 9.4).

Invertebrate communities can be described by representation of groups of organisms that use resources in similar ways (table 5). The resource type most commonly used in such characterizations is food. The availability of food resources changes along gradients of environmental characteristics such as drainage area and stream order (Vannote and others, 1980). Energy sources change from coarse particulate organic matter (CPOM) of terrestrial origin to a combination of in-stream primary production and downstream transport of fine particulate organic matter (FPOM) as one moves from headwaters to downstream reaches (Vannote and others, 1980). Benthic invertebrates are grouped by feeding habit into functional feeding groups (FFG). These include collector-gatherers (detritivores such as those that feed on deposits of fine particulate organic matter), collector-filterers (those that use suspended fine particulate organic matter), scrapers (which graze periphyton), predators, and shredders (which consume coarse particulate organic matter). The River Continuum Concept (Vannote and others, 1980) predicts that proportions of functional feeding groups should change in response to the change in food from coarse particulate organic matter to fine particulate organic matter along a gradient of stream size.

Collector-gatherers dominated 12 of 19 riffle samples and represented over 50 percent of all individuals in the sample from Peters Creek, all samples from Clear Fork, and the 1997 Reed Creek sample (fig. 4a). Collector-filterers were the dominant group in two samples from the Williams River at Dyer, Little River at Graysontown, and the Kanawha River at Kanawha Falls (fig. 4b). Collector-filterer relative abundance was greatest at Kanawha Falls, where the greatest transport of FPOM would be expected. Scrapers represented the greatest portion of the samples from Bluestone River, New River at Glen Lyn, and the New River at Thurmond (fig. 4c). In-stream production of biomass is more important in larger streams, such as at the integrator sites, and nutrient-enriched streams, such as the Bluestone River (Allan, 1995), and greater periphyton production can support greater scraper populations.

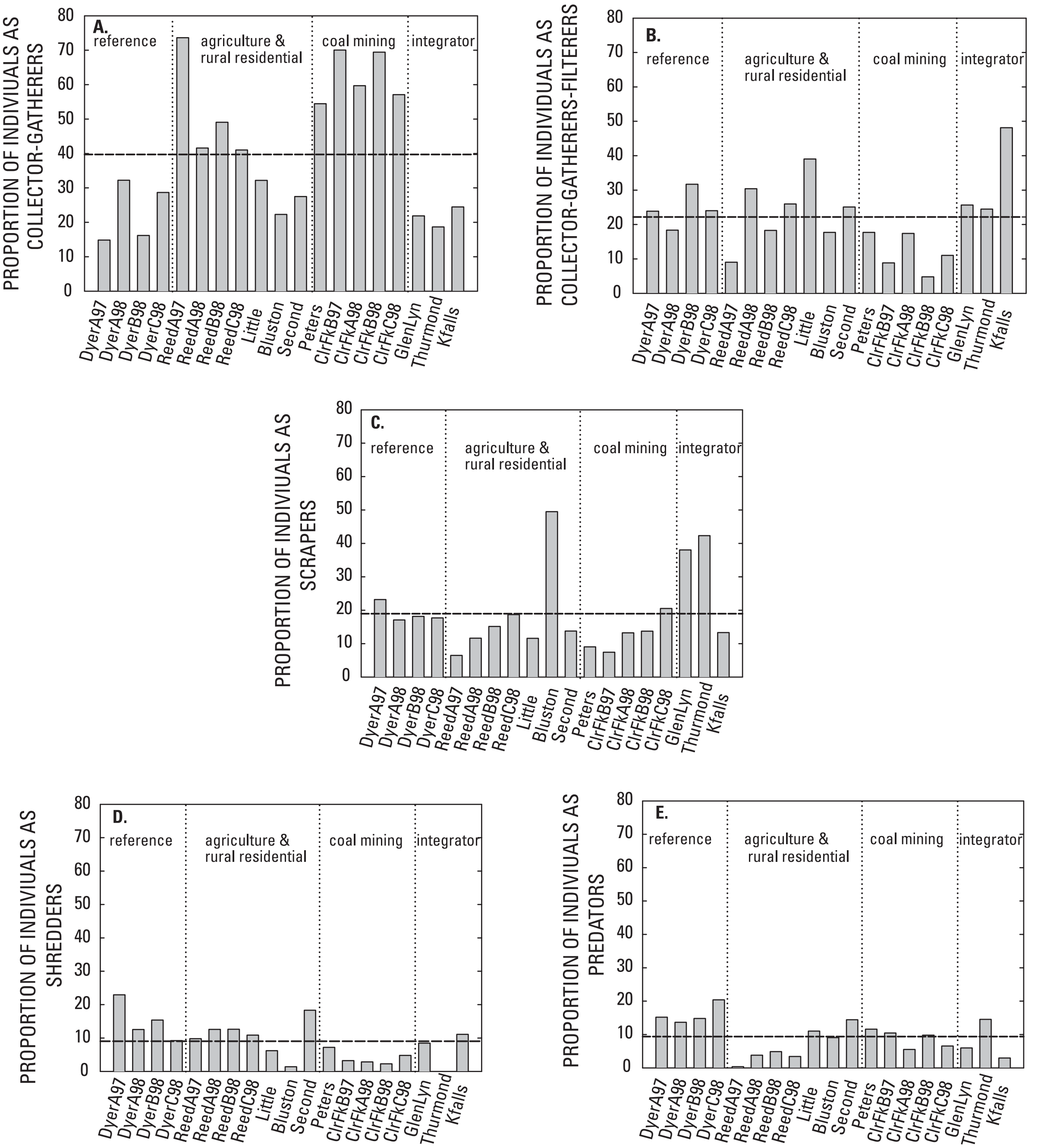

Figure 4 a-e. Proportions of (A.) collector-gatherers, (B.) collector-filterers, (C.) scrapers, (D.) shredders, and (E.) predators in May-June samples for sites representing selected environmental settings in the Kanawha River Basin. (Dashed lines indicate mean values for all samples. Full names of sites are given in tables 1 and 2).

Neither shredders nor predators dominated any sample. Shredders were most abundant in samples from Williams River at Dyer, Second Creek near Second Creek, and samples from Reed Creek. No shredder taxa were found at New River at Thurmond. The absence of shredder taxa at integrator sites can easily be explained by their preference for CPOM, which makes up a relatively smaller fraction of the available energy resources in larger streams such as those sampled at the integrator sites. Low shredder abundance at Peters Creek and Clear Fork is probably related to habitat degradation such as siltation, of which many shredder taxa are intolerant. Predators ranged in relative abundance from 0.4 percent in the 1997 sample from Reed Creek, reach A, to 20 percent in the Williams River at Dyer, reach C sample collected in 1998. Predators, because of their high position in food webs, are not expected to numerically dominate communities.

The Hilsenhoff Biotic index (HBI) was originally designed as an index of organic-pollution degradation based upon family-level data (fig. 5a) (Hilsenhoff, 1988). The index is an abundance-weighted average of pollution-tolerance values assigned to each taxon. High tolerance values are assigned to tolerant taxa and low values to taxa sensitive to pollution (table 6). Low HBI scores indicate low levels of impairment and higher scores indicate increased impairment. We used a modification of the HBI using generic-level data and pollution-tolerance scores from Bode and others (1996). Sample scores for the Hilsenhoff Biotic Index ranged from 2.84 for the Williams River at Dyer (reach C sample from 1998) to 5.80 for the Kanawha River at Kanawha Falls. The mean score was 4.44 and the median was 4.51. The mean reference site score was 3.41 (range 2.84-3.77, s.d. 0.40). A pattern of high HBI scores for integrator sites and samples from Clear Fork is evident, reflecting a grouping of samples similar to that seen for taxa richness, number of EPT taxa, and proportion of EPT taxa metrics. Consistent with this pattern, Peters Creek reflects lower levels of impairment than does Clear Fork. HBI scores for the agricultural indicator sites were lower than those for the mining sites, but still higher than the reference condition mean.

The ratio of intolerant taxa abundance in a sample to the abundance of tolerant taxa is used as a measure of impairment; the ratio increases with decreased community impairment. We used the ratio of EPT abundance to the combined abundances of Chironomidae and EPT (fig. 5b). Values for the EPT/Chironomidae+EPT ratio varied from 0.02 at the Kanawha River at Kanawha Falls to 0.71 in the Williams River at Dyer, reach A sample collected in 1998. The reference condition mean was 0.59 (range 0.44-0.71, s.d. 0.11), which was exceeded by three Williams River at Dyer samples and the 1998 sample from Clear Fork, reach A. Although this ratio was highly variable, it was generally lower than the reference-condition average of both coal-mining and agricultural indicator sites. At integrator sites, the ratio displayed no pattern other than being lower than the reference condition.

As environmental conditions are degraded, groups of sensitive taxa decrease in abundance, and a few tolerant species increase in the absence of competition from the intolerant taxa. The increasing dominance of a sample by a few taxa usually indicates increasing impairment. The proportion of a sample represented by the two most abundant, or dominant, taxa ranged from 18 percent in the Reed Creek, reach B sample collected in 1998 to 59 percent in the Clear Fork, reach B sample collected in 1997 (fig. 5c). The mean value for all four Williams River at Dyer samples was 22 percent (range 21.7 percent-22.8 percent, s.d. 0.46). Again, the integrators and Clear Fork samples show the greatest departure from the reference condition, and in this case the Peters Creek mining-indicator site has values more similar to the agricultural indicators.

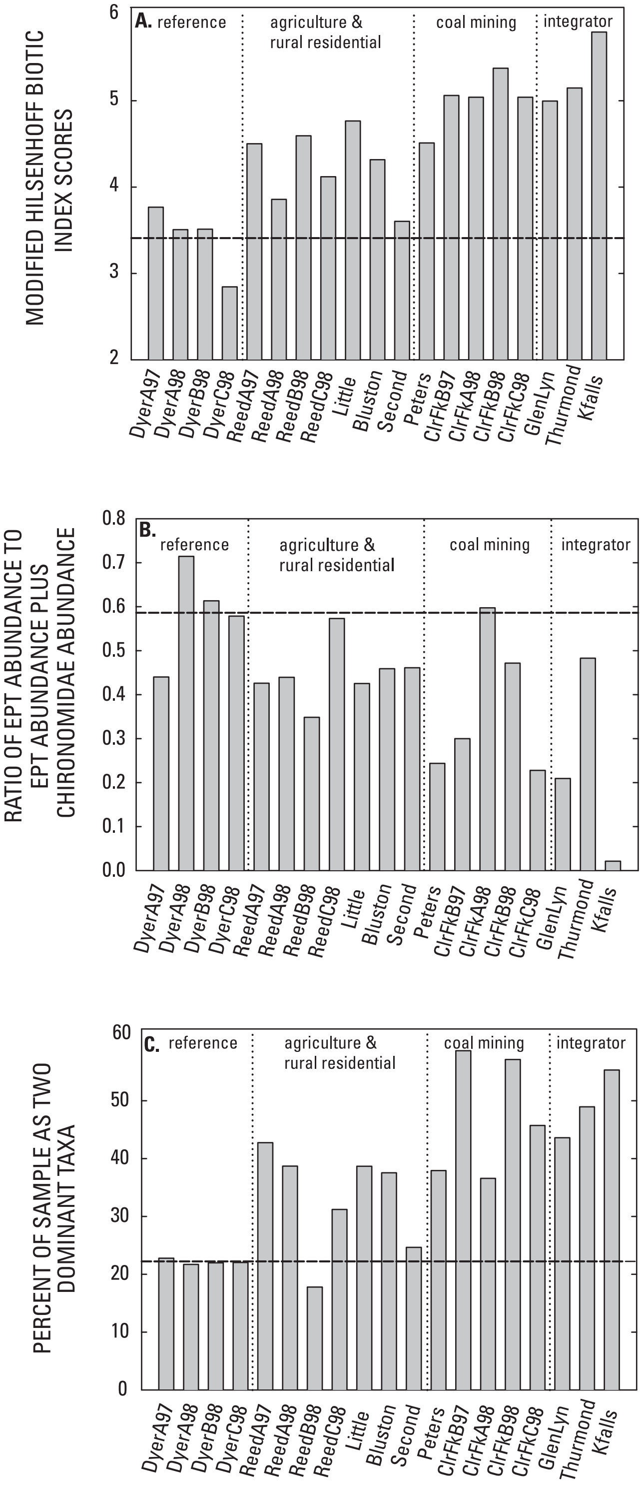

Figure 5 a-c. Pollution tolerance metric values for (A.) Modified Hilsenhoff Biotic Index, (B.) ratio of abundance of EPT taxa to abundance of Chironomidae and EPT taxa, and (C.) percent of sample comprised of the two dominant taxa for sites representing selected environmental settings in the Kanawha River Basin. (Dashed lines indicate the mean value for reference condition samples from the Williams River at Dyer. EPT=Ephemeroptera, Plecoptera, and Trichoptera taxa. Full names of sites given in tables 1 and 2.)

Table 6. Taxa collected, functional feeding groups, and pollution tolerance values for the modified Hilsenhoff Biotic Index for samples from riffle habitats in the Kanawha River Basin, 1997-1998

[c-f, collector-filterer; c-g, collector-gatherer; scr, scraper; shr, shredder; prd, predator, For each taxon a short name is provided for use in graphs. Taxa are listed in phylogenetic order (Thorp and Covich, 1991, Merritt and Cummins, 1996)*, Bode and others, 1996]

Order or higher taxa	family	Taxa Name	Short name	Functional Feeding Group*	Pollution Tolerance Value*
Phylum Platyhelminthes					
Class Turbellaria		Turbellaria	Tur_CL	c-g	6
Phylum Nematoda		Nematoda	Nemtod	c-g	6
Class Oligochaeta		Oligochaeta	Oli_CL	c-g	8
Super Order Megadrile		Megadrile	MegaSO	c-g	8
Lumbriculida	Lumbriculidae	Lumbriculidae	Lum_FM	c-g	8
Haplotaxida	Naididae	Naididae	Nai_FM	c-g	6
Haplotaxida	Tubificidae	Tubificidae	Tub_FM	c-g	10
Class Hirudinea		Hirudinea	Hir_CL	prd	7
Phylum Mollusca					
Class Gastropoda		Gastropoda	GSTRPOD	scr	5
Basomattophora	Ancylidae		Anc_FM	scr	6
Neotaenioglossa	Pleuroceridae	*Elimia* sp.	Eli_sp	scr	6
Neotaenioglossa	Pleuroceridae	*Leptoxis* sp.	Let_sp	scr	6
Neotaenioglossa	Pleuroceridae	*Pleurocera* sp.	Ple_sp	scr	6
Class Bivalvia					
Veneroida	Corbiculidae	*Corbicula* sp.	Cor_sp	c-f	6
Veneroida	Sphaeriidae	*Sphaerium* sp.	Spha_sp	c-f	6
Phylum Arthropoda					
Class Arachnida					
Subclass Acarina		Hydrachnidia	Hyd_OR	prd	6
Class Malacostraca					
Isopoda	Asellidae	*Caecidotea* sp.	Cae_sp	c-g	8
Amphipoda	Gammaridae	*Gammarus* sp.	Gam_sp	c-g	6
Decapoda	Cambaridae	*Cambarus* sp.	Cam_sp	c-g	6
Decapoda	Cambaridae	*Orconectes* sp.	Orc_sp	c-g	6
Class Insecta					

Table 6. Taxa collected, functional feeding groups, and pollution tolerance values for the modified Hilsenhoff Biotic Index for samples from riffle habitats in the Kanawha River Basin, 1997-1998 —Continued

[c-f, collector-filterer; c-g, collector-gatherer; scr, scraper; shr, shredder; prd, predator, For each taxon a short name is provided for use in graphs. Taxa are listed in phylogenetic order (Thorp and Covich, 1991, Merritt and Cummins, 1996)*, Bode and others, 1996]

Order or higher taxa	family	Taxa Name	Short name	Functional Feeding Group*	Pollution Tolerance Value*
Collembola		Collembola	Coll_OR	c-g	5
Ephemeroptera	Baetidae	*Acentrella* sp.	Ace_sp	c-g	4
Ephemeroptera	Baetidae	*Baetis* sp.	Bae_sp	c-g	6
Ephemeroptera	Baetidae	*Centroptilum*/ *Procloeon* sp.	Cent/Pro	c-g	2
Ephemeroptera	Baetidae	*Heterocloeon* sp.	Het_sp	scr	2
Ephemeroptera	Baetidae	*Plauditus* sp.	Plau_sp	c-g	6
Ephemeroptera	Isonychiidae	*Isonychia* sp.	Iso_sp	c-g	2
Ephemeroptera	Heptageniidae	*Epeorus* sp.	Epe_sp	scr	0
Ephemeroptera	Heptageniidae	*Heptagenia* sp.	Hep_sp	scr	4
Ephemeroptera	Heptageniidae	*Leucrocuta* sp.	Leu_sp	scr	1
Ephemeroptera	Heptageniidae	*Stenacron* sp.	Ste_sp	scr	7
Ephemeroptera	Heptageniidae	*Stenonema* sp.	Sto_sp	scr	3
Ephemeroptera	Ephemerellidae	*Drunella* sp.	Dru_sp	scr	0
Ephemeroptera	Ephemerellidae	*Ephemerella* sp.	Efe_sp	c-g	1
Ephemeroptera	Ephemerellidae	*Eurylophella* sp.	Eur_sp	c-g	2
Ephemeroptera	Ephemerellidae	*Serratella* sp.	Ser_sp	c-g	2
Ephemeroptera	Ephemerellidae	*Timpanoga* sp.	Tim_sp	c-g	2
Ephemeroptera	Leptohyphidae	*Tricorythodes* sp.	Trc_sp	c-g	4
Ephemeroptera	Caenidae	*Caenis* sp.	Cae_sp	c-g	6
Ephemeroptera	Leptophlebiidae	*Paraleptophlebia* sp.	Pal_sp	c-g	1
Ephemeroptera	Potamanthidae	*Anthopotamus* sp.	Ant_sp	c-g	4
Ephemeroptera	Ephemeridae	*Ephemera guttulata* Pictet	Ephgut	c-g	2
Odonata	Gomphidae	*Ophiogomphus* sp.	Oph_sp	prd	1
Odonata	Aeshnidae	*Boyeria grafiana* Williamson	Boygra	prd	2
Odonata	Macromiidae	*Macromia taeniolata* Rambur	Mac_tae	prd	2
Odonata	Coenagrionidae	*Argia* sp.	Arg_sp	prd	6
Plecoptera	Pteronarcyidae	*Pteronarcys* sp.	Pte_sp	shr	0
Plecoptera	Peltoperlidae	*Peltoperla* sp.	Plto_sp	shr	0

Table 6. Taxa collected, functional feeding groups, and pollution tolerance values for the modified Hilsenhoff Biotic Index for samples from riffle habitats in the Kanawha River Basin, 1997-1998 —Continued

[c-f, collector-filterer; c-g, collector-gatherer; scr, scraper; shr, shredder; prd, predator, For each taxon a short name is provided for use in graphs. Taxa are listed in phylogenetic order (Thorp and Covich, 1991, Merritt and Cummins, 1996)*, Bode and others, 1996]

Order or higher taxa	family	Taxa Name	Short name	Functional Feeding Group*	Pollution Tolerance Value*
Plecoptera	Peltoperlidae	*Tallaperla* sp.	Talla_sp	shr	0
Plecoptera	Nemouridae	*Amphinemura* sp.	Amp_sp	shr	3
Plecoptera	Leuctridae	*Leuctra* sp.	Luc_sp	shr	0
Plecoptera	Leuctridae	*Paraleuctra* sp.	Prl_sp	shr	0
Plecoptera	Perlidae	*Acroneuria* sp.	Acr_sp	prd	0
Plecoptera	Perlidae	*Agnetina* sp.	Agn_sp	prd	2
Plecoptera	Perlidae	*Neoperla* sp.	Neo_sp	prd	3
Plecoptera	Perlidae	*Paragnetina immarginata* (Say)	Prgimm	prd	1
Plecoptera	Perlidae	*Perlesta* sp.	Per_sp	prd	5
Plecoptera	Perlodidae	*Isoperla* sp.	Isp_sp	prd	2
Plecoptera	Chloroperlidae	*Suwallia* sp.	Suw_sp	prd	0
Plecoptera	Chloroperlidae	*Sweltsa* sp.	Swel_sp	prd	0
Hemiptera	Veliidae	*Rhagovelia* sp.	Rha_sp	prd	5
Megaloptera	Corydalidae	*Corydalus cornutus* (Linnaeus)	Corcor	prd	4
Megaloptera	Corydalidae	*Nigronia* sp.	Nig_sp	prd	0
Megaloptera	Sialidae	*Sialis* sp.	Sia_sp	prd	4
Trichoptera	Philopotamidae	*Chimarra* sp.	Chim_sp	c-f	4
Trichoptera	Philopotamidae	*Dolophilodes* sp.	Dol_sp	c-f	0
Trichoptera	Psychomyiidae	*Psychomyia* sp.	Psy_sp	c-g	2
Trichoptera	Polycentropodidae	*Paranyctiophylax* sp.	Pan_sp	prd	6
Trichoptera	Polycentropodidae	*Polycentropus* sp.	Pol_sp	prd	6
Trichoptera	Hydropsychidae	*Ceratopsyche* sp.	Cer_sp	c-f	5
Trichoptera	Hydropsychidae	*Cheumatopsyche* sp.	Chu_sp	c-f	5
Trichoptera	Hydropsychidae	*Hydropsyche* sp.	Hyd_sp	c-f	4
Trichoptera	Rhyacophilidae	*Rhyacophila* sp.	Rhy_sp	prd	1
Trichoptera	Glossosomatidae	*Agapetus* sp.	Aga_sp	scr	0
Trichoptera	Glossosomatidae	*Glossosoma* sp.	Glo_sp	scr	0
Trichoptera	Glossosomatidae	*Protoptila* sp.	Prt_sp	scr	1

Table 6. Taxa collected, functional feeding groups, and pollution tolerance values for the modified Hilsenhoff Biotic Index for samples from riffle habitats in the Kanawha River Basin, 1997-1998 —Continued

[c-f, collector-filterer; c-g, collector-gatherer; scr, scraper; shr, shredder; prd, predator, For each taxon a short name is provided for use in graphs. Taxa are listed in phylogenetic order (Thorp and Covich, 1991, Merritt and Cummins, 1996)*, Bode and others, 1996]

Order or higher taxa	family	Taxa Name	Short name	Functional Feeding Group*	Pollution Tolerance Value*
Trichoptera	Hydroptilidae	*Hydroptila* sp.	Hyr_sp	scr	6
Trichoptera	Hydroptilidae	*Leucotrichia* sp.	Leu_sp	scr	6
Trichoptera	Hydroptilidae	*Mayatrichia ayama* Mosely	May_aya	scr	6
Trichoptera	Hydroptilidae	*Ochrotrichia* sp.	Ochr_sp	scr	6
Trichoptera	Brachycentridae	*Brachycentrus* sp.	Bra_sp	c-f	1
Trichoptera	Brachycentridae	*Micrasema* sp.	Mic_sp	shr	2
Trichoptera	Lepidostomatidae	*Lepidostoma* sp.	Lep_sp	shr	1
Trichoptera	Limnephilidae	*Pycnopsyche* sp.	Pyc_sp	shr	4
Trichoptera	Apataniidae	*Apatania* sp.	Apa_sp	scr	3
Trichoptera	Goeridae	*Goera* sp.	Goe_sp	scr	3
Trichoptera	Uenoidae	*Neophylax* sp.	Nph_sp	scr	3
Trichoptera	Helicopsychidae	*Helicopsyche borealis* (Hagen)	Helbor	scr	3
Trichoptera	Odontoceridae	*Psilotreta labida* Ross	Psilab	scr	0
Trichoptera	Leptoceridae	*Ceraclea* sp.	Cea_sp	c-g	3
Trichoptera	Leptoceridae	*Mystacides sepulchralis* (Walker)	Myssep	c-g	4
Trichoptera	Leptoceridae	*Nectopsyche* sp.	Nec_sp	shr	3
Trichoptera	Leptoceridae	*Oecetis* sp.	Oec_sp	prd	5
Lepidoptera	Pyralidae	*Petrophila* sp.	Pet_sp	scr	5
Coleoptera	Gyrinidae	*Dineutus* sp.	Din _sp	prd	4
Coleoptera	Elmidae	*Ancyronyx variegata* (Germar)	Ancvar	c-g	5
Coleoptera	Elmidae	*Dubiraphia* sp.	Dub_sp	c-g	6
Coleoptera	Elmidae	*Macronychus glabratus* Say	Macgla	c-g	5
Coleoptera	Elmidae	*Microcylloepus pusillus* (LeConte)	Mcy_pus	scr	3
Coleoptera	Elmidae	*Optioservus* sp.	Opt_sp	scr	4
Coleoptera	Elmidae	*Oulimnius latiusculus* (LeConte)	Oullat	scr	4
Coleoptera	Elmidae	*Promoresia* sp.	Prm_sp	scr	2

Table 6. Taxa collected, functional feeding groups, and pollution tolerance values for the modified Hilsenhoff Biotic Index for samples from riffle habitats in the Kanawha River Basin, 1997-1998 —Continued

[c-f, collector-filterer; c-g, collector-gatherer; scr, scraper; shr, shredder; prd, predator, For each taxon a short name is provided for use in graphs. Taxa are listed in phylogenetic order (Thorp and Covich, 1991, Merritt and Cummins, 1996)*, Bode and others, 1996]

Order or higher taxa	family	Taxa Name	Short name	Functional Feeding Group*	Pollution Tolerance Value*
Coleoptera	Elmidae	*Stenelmis* sp.	Stn_sp	scr	5
Coleoptera	Psephenidae	*Ectopria* sp.	Ect_sp	scr	5
Coleoptera	Psephenidae	*Psephenus herricki* (DeKay)	Pseher	scr	4
Coleoptera	Staphylinidae	Staphylinidae	Sta_FM	prd	5
Diptera		Nematocera	Ncera_SO	--	--
Diptera	Blephariceridae	*Blepharicera* sp.	Ble_sp	c-g	0
Diptera	Ceratopogonidae	*Atrichopogon* sp.	Atric_sp	prd	6
Diptera	Ceratopogonidae	*Bezzia*/*Palpomyia* sp.	Bez/Pal	prd	6
Diptera	Ceratopogonidae	*Dasyhelea* sp.	Das_sp	c-g	6
Diptera	Ceratopogonidae	*Probezzia* sp.	Prob_sp	prd	6
Diptera	Chironomidae	*Ablabesmyia* sp.	Abl_sp	prd	8
Diptera	Chironomidae	*Labrundinia* sp.	labr_sp.	prd	7
Diptera	Chironomidae	*Thienemannimyia* group sp.	Thi_G	prd	6
Diptera	Chironomidae	*Zavrelimyia* sp.	Zacr_sp	prd	8
Diptera	Chironomidae	*Diamesa* sp.	Dia_sp	c-g	5
Diptera	Chironomidae	*Pagastia* sp.	Pag_sp	c-g	1
Diptera	Chironomidae	*Potthastia* sp.	Pot_sp	c-g	2
Diptera	Chironomidae	*Corynoneura* sp.	Cory_sp	c-g	4
Diptera	Chironomidae	*Thienemanniella* sp.	Thi_sp	c-g	6
Diptera	Chironomidae	*Brillia* sp.	Bri_sp	shr	5
Diptera	Chironomidae	*Cardiocladius* sp.	Car_sp	prd	5
Diptera	Chironomidae	*Cricotopus bicinctus* group	CribicG	scr	7
Diptera	Chironomidae	*Cricotopus* sp.	Cri_sp	shr	7
Diptera	Chironomidae	*Cricotopus trifascia* group	CritriG	shr	6
Diptera	Chironomidae	*Cricotopus*/ *Orthocladius* sp.	Cr/Or_sp	c-g	6
Diptera	Chironomidae	*Eukiefferiella* sp.	Euk_sp	c-g	4
Diptera	Chironomidae	*Lopescladius* sp.	Lop_sp	c-g	4

Table 6. Taxa collected, functional feeding groups, and pollution tolerance values for the modified Hilsenhoff Biotic Index for samples from riffle habitats in the Kanawha River Basin, 1997-1998 —Continued

[c-f, collector-filterer; c-g, collector-gatherer; scr, scraper; shr, shredder; prd, predator, For each taxon a short name is provided for use in graphs. Taxa are listed in phylogenetic order (Thorp and Covich, 1991, Merritt and Cummins, 1996)*, Bode and others, 1996]

Order or higher taxa	family	Taxa Name	Short name	Functional Feeding Group*	Pollution Tolerance Value*
Diptera	Chironomidae	*Nanocladius* sp.	Nclad_sp	c-g	7
Diptera	Chironomidae	*Orthocladius* (*Symposiocladius*) sp.	OrtSym	c-g	6
Diptera	Chironomidae	*Orthocladius* sp.	Or_sp	c-g	6
Diptera	Chironomidae	*Parachaetocladius* sp.	Prch_sp	c-g	2
Diptera	Chironomidae	*Parakiefferiella* sp.	Pak_sp	c-g	4
Diptera	Chironomidae	*Parametriocnemus* sp.	Pam_sp	c-g	5
Diptera	Chironomidae	*Pseudosmittia* sp.	Pss_sp	c-g	5
Diptera	Chironomidae	*Rheocricotopus* sp.	Rhe_sp	c-g	6
Diptera	Chironomidae	*Synorthocladius* sp.	Syn_sp	c-g	6
Diptera	Chironomidae	*Tvetenia* sp.	Tve_sp	c-g	5
Diptera	Chironomidae	*Chironomus*/ *Einfeldia* sp.	Chi_sp	c-g	10
Diptera	Chironomidae	*Cryptochironomus* sp.	Cry_sp	prd	5
Diptera	Chironomidae	*Dicrotendipes* sp.	Dit_sp	c-g	8
Diptera	Chironomidae	*Microtendipes* sp.	Mcr_sp	c-f	5
Diptera	Chironomidae	*Phaenopsectra* sp.	Pha_sp	scr	7
Diptera	Chironomidae	*Phaenopsectra*/ *Tribelos* sp.	Ph/Tr_sp	scr	7
Diptera	Chironomidae	*Polypedilum* sp.	Pop_sp	shr	6
Diptera	Chironomidae	*Robackia* sp.	Rob_sp	c-g	6
Diptera	Chironomidae	*Saetheria* sp.	Sae_sp	c-g	4
Diptera	Chironomidae	*Stenochironomus* sp.	Stc_sp	c-g	5
Diptera	Chironomidae	*Tribelos* sp.	Trb_sp	c-g	7
Diptera	Chironomidae	*Pseudochironomus* sp.	Psc_sp	c-g	5
Diptera	Chironomidae	*Cladotanytarsus* sp.	Cla_sp	c-f	5
Diptera	Chironomidae	*Constempellina* sp.	Con_sp	c-g	4
Diptera	Chironomidae	*Krenopsectra*/ *Micropsectra* sp.	Kre/Mic	c-g	7

Table 6. Taxa collected, functional feeding groups, and pollution tolerance values for the modified Hilsenhoff Biotic Index for samples from riffle habitats in the Kanawha River Basin, 1997-1998 —Continued

[c-f, collector-filterer; c-g, collector-gatherer; scr, scraper; shr, shredder; prd, predator, For each taxon a short name is provided for use in graphs. Taxa are listed in phylogenetic order (Thorp and Covich, 1991, Merritt and Cummins, 1996)*, Bode and others, 1996]

Order or higher taxa	family	Taxa Name	Short name	Functional Feeding Group*	Pollution Tolerance Value*
Diptera	Chironomidae	*Micropsectra* sp.	Mic_sp	c-g	7
Diptera	Chironomidae	*Micropsectra*/ *Tanytarsus* sp.	Mic/Tan	c-g	7
Diptera	Chironomidae	*Neozavrelia* sp.	Neoz_sp	c-g	6
Diptera	Chironomidae	*Paratanytarsus* sp.	Prtsp	c-f	6
Diptera	Chironomidae	*Rheotanytarsus* sp.	Rht_sp	c-f	6
Diptera	Chironomidae	*Stempellinella* sp.	Stm_sp	c-g	2
Diptera	Chironomidae	*Sublettea* sp.	Sub_sp	c-f	4
Diptera	Chironomidae	*Tanytarsus* sp.	Tta_sp	c-f	6
Diptera	Simuliidae	*Simulium* sp.	Sim_sp	c-f	5
Diptera	Tanyderidae	Tanyderidae	Tde_FM	--	5
Diptera	Tipulidae	*Antocha* sp.	Ano_sp	c-g	3
Diptera	Tipulidae	*Dicranota* sp.	Dic_sp	prd	3
Diptera	Tipulidae	*Hexatoma* sp.	Hex_sp	prd	2
Diptera	Tipulidae	*Lipsothrix* sp.	Lips_sp	shr	4
Diptera	Tipulidae	*Tipula* sp.	Tip_sp	shr	6
Diptera	Athericidae	*Atherix lantha* Webb	Athe_lan	prd	4
Diptera	Empididae	*Chelifera*/ *Hemerodromia* sp.	Ch/He_sp	prd	6

Comparison of Communities in Kanawha River Coal-Mining Region

In the coal-mining synoptic survey, reference conditions were first defined by identifying sites representing basins with no history of mining. From this group of four unmined sites, three were used to calculate a mean reference condition, Mill Creek at Hopewell, Millers Creek at Nallen, and Laurel Fork at Hacker Valley. The fourth unmined site, Little Sandy Creek at Wills, experienced a major flood six weeks before sampling, which acutely disturbed the benthic community. Two of the three reference sites, Millers Creek and Laurel Fork, were the two smallest basins sampled as part of this study, and both basin area and location within the river continuum strongly affect community structure. These sites still represented the minimally affected condition in the coal-mining region of the Kanawha River Basin, and we used the mean of metric values from these three sites for comparison to the rest of the sites.

As with the fixed-site network, we compared metrics that describe species composition, trophic structure, and pollution tolerance. Figures 6 through 8 present metric values for samples with sites arranged by mining history, using 1980 as the date when the regulatory changes brought about by SMCRA would have been implemented. Although SMCRA pertains only to surface mining, all basins mined after 1980 were mined using both surface- and deep-mining techniques. Unmined sites are at the left of the bar graphs. Sites mined before 1980, but not since, and by using only underground mining techniques are to their right; followed by basins mined before 1980, but not since, and using multiple mining methods; and lastly sites mined from 1980 through 1995 in ascending order of basin mean 1980-1995 coal production. Generally, a pattern of increasing impairment is seen as mining intensity increases; metric values for many sites that were deep mined before 1980 were similar to those for reference conditions.

The number of taxa found in samples from the coal-mining region ranged from 22 taxa at Kellys Creek at Cedar Grove to 53 taxa at Gauley River above Williams River (fig. 6a). The mean and median values were both 38 taxa per sample. The mean value for the reference sites was 40 (range 37-44, s.d. 3.5). The most intensively mined sites differed most significantly from the reference condition. Two other sites—the unmined but recently flooded Little Sandy Creek and the highly modified Davis Creek—supported few taxa.

The number of EPT taxa ranged from three taxa at Davis Creek at Trace Fork to 30 at Williams River at Dyer. The mean reference-condition value was 22 (range 17-25, s.d. 4.6). As with overall taxa richness, EPT taxa richness decreased with increasing coal production. EPT taxa richness, however, was more variable in response to mining intensity than overall taxa richness. This finding may be due in part to the effects of land uses other than mining, such as agricultural, residential and commercial areas, but also to the relatively greater tolerance of some Trichopterans to environmental changes due to coal-mining (Allan, 1995). These land uses represent a particularly strong influence in the Davis Creek Basin, which has a high proportion of residential areas and where several large cut-and-fill construction projects were underway in 1998.

The percentage of individuals represented by EPT taxa varied widely, from a low of 2.7 percent at Davis Creek to a high of 82 percent in the sample from Williams River at Handley Wildlife Management Area (WMA), reach A (Handley1 on fig. 6c). The mean reference-condition value was 68 percent (range 60 percent-80 percent, s.d. 11). Proportional representation of EPT taxa was highest in unmined basins and basins that had been only deep mined before 1980. Several of these basins are also in the Allegheny Highlands portions of the Appalachian Plateaus. The value of this metric for Little Sandy Creek exceeded the reference site mean, suggesting that even though the number of total and EPT taxa probably declined due to the flood disturbance, the proportion of EPT taxa remained high and indicative of the lack of mining disturbance.

As with proportion of EPT taxa, the percent of a sample represented by Chironomidae had a wide range, from a low of 6.4 percent at Camp Creek to a high of 63 percent at Kellys Creek (fig. 6d). The mean value for the reference sites was 15 percent (range 9 percent-24 percent, s.d. 11). In a pattern complementary to that of proportion of EPT taxa, proportion of midges was lowest in unmined sites and basins deep mined before 1980. No other readily discernible pattern was detected in midge representation.

Functional feeding groups, although useful for describing sites, respond variably to environmental conditions (fig. 7a-e). Large departures from an average condition, however, may indicate some level of environmental stress. Collector-filterers and collector-gatherers—organisms that consume fine and coarse particulate organic material—dominated the samples. Collector-filterers averaged 34 percent of samples; collector-gatherers averaged 31 percent. Samples that departed from this pattern include Davis Creek where only 2 percent of the individuals were collector-filterers, Spruce Laurel Fork at Clothier, where collector-filterers made up nearly 70 percent of individuals, and Kellys Creek, where nearly 70 percent of the individuals were collector-gatherers. After the collector groups, scrapers represented the next largest fraction of samples with an average of 20 percent. Of all the feeding groups examined, only shredder representation varied consistently with level of mining and degradation. Shredders preferentially inhabit smaller, headwater streams where their food resources are most abundant (Vannote and others, 1980). Also, many shredders cannot tolerate environmental degradation (Barbour and others, 1999). Shredders were most abundant in the smallest basins with little anthropogenic disturbance, namely Laurel Fork at Hacker Valley (18 percent), Millers Creek (15 percent), and the two replicates from North Fork Cherry River near Richwood (14 percent and 13 percent).

The modified Hilsenhoff Biotic Index (HBI), an abundance-weighted average of species tolerance to pollution, ranged from 2.84 at Williams River at Handley WMA, reach B (Handley2), to 5.61 at Cabin Creek at Dry Branch (fig. 8a). The reference-condition mean was 3.46 (range 3.04-3.99, s.d. 0.49), which compares favorably with the fixed-site network reference condition mean HBI score of 3.2. The HBI scores for samples increased with increasing coal production, the response being strongest at higher levels of production. High scores for samples from basins with little or no coal production were related to other sources of disturbances such as flooding (Little Sandy Creek), construction and residences (Davis Creek), or stream-channel modification (Sewell Creek). The HBI can indicate many forms of stream degradation other than the organic pollution for which it was originally designed.

The ratio of EPT taxa to EPT and Chironomidae measures relative abundances of intolerant to tolerant taxa groups (fig. 8b). Values ranged from 0.043 for both Big Horse Creek and Davis Creek to 0.87 for Little Sandy Creek at Wills. The mean reference-site values averaged 0.65 (range 0.54-0.71, s.d. 0.09). The ratio of intolerant EPT to tolerant midges and EPT taxa combined indicates increasing impairment correlates with increasing coal production. Little indication of impairment was evident in basins either unmined or only deep mined before 1980.

The proportion of a sample represented by the two dominant taxa ranged from 22 percent of the sample at Sewell Creek to 64 percent at Davis Creek (fig. 8c). Reference sites averaged 34 percent (range 28 percent-38 percent, s.d. 5.2). This metric was useful in differentiating between impaired and unimpaired sites in the fixed-site network. In the case of the synoptic sites, however, the proportion of the two dominant taxa was of little value in differentiating sites.

Sites where little or no recent mining has occurred have metric values similar to those in basins that have never been mined. Basins that were only deep mined before 1980 were most similar to the unmined conditions. These basins all had much smaller recoverable coal reserves than basins mined since 1980; the general pattern was that most basins with extensive mineable coal had been mined almost continuously using a variety of techniques.

Community impairment increased with increasing coal production. However, there was also evidence of community impairment due to land-use practices other than mining. Basins with extensive non-mining disturbances, such as construction at Davis Creek or channel dredging and riparian area clearing at Sewell Creek, had metric values as suggestive of impairment as did basins with high coal production. The habitat effects of construction may be short lived (Chisholm and Downs, 1978). Coal mining is the most important disturbance in the Kanawha River Basin because it is the most extensive

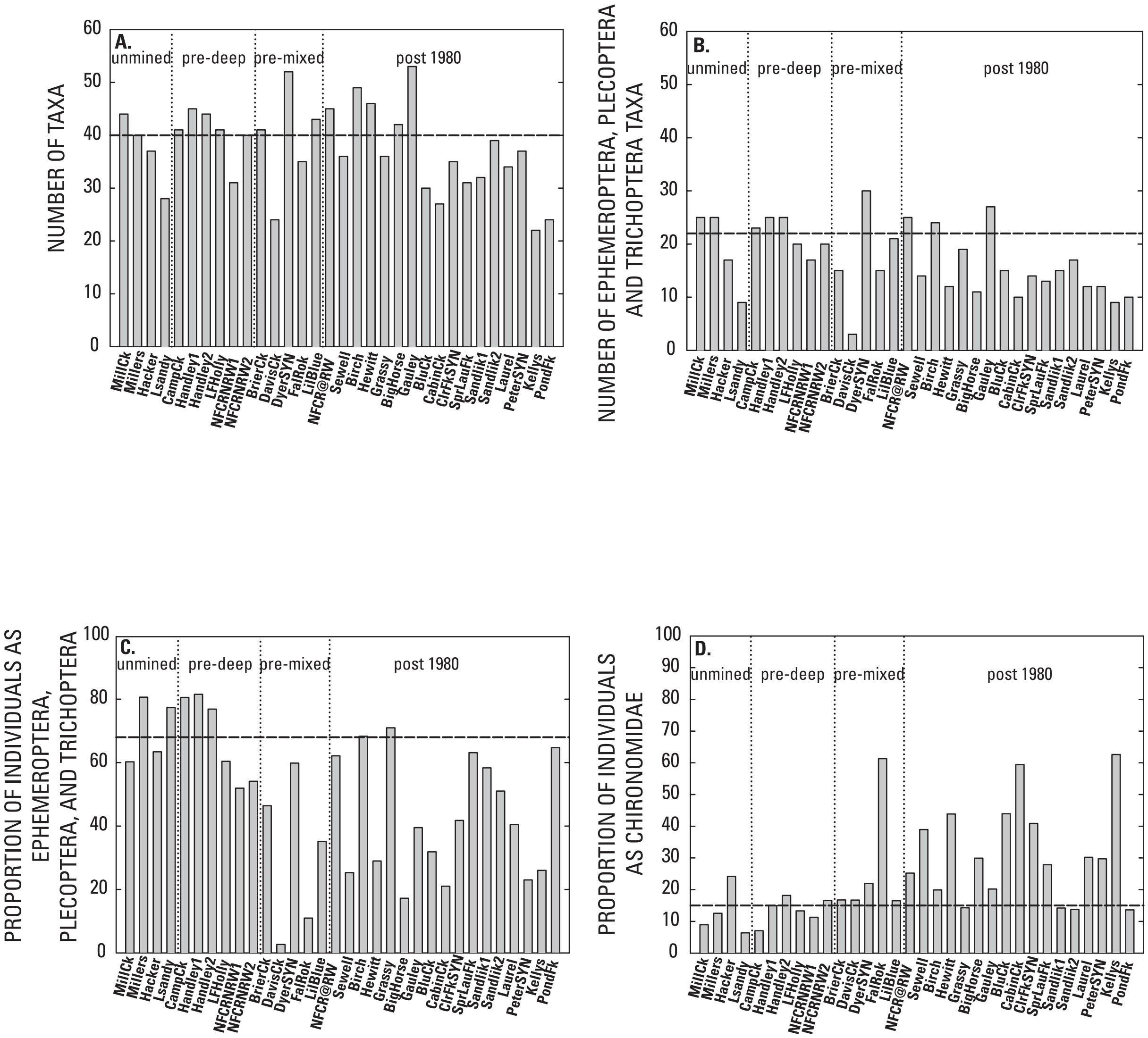

Figure 6 a-d. Community composition metric values showing (A.) taxa richness, (B.) number of Ephemeroptera, Plecoptera, and Trichoptera taxa, (C.) proportion of individuals as Ephemeroptera, Plecoptera, and Trichoptera, and (D.) proportion of individuals as Chironomidae for coal-mining synoptic-survey sites in the Kanawha River Basin. (Dashed lines indicate mean values for metrics at reference sites, Mill Creek near Hopewell, Millers Creek at Nallen, and Laurel Fork at Hacker Valley. Sites are grouped on the basis of mining history and represented as unmined; pre-deep, only deep mined before 1980; pre-mixed, both deep and surface mined before 1980; post 1980, both deep and surface mined before and since 1980. Full names of sites given in tables 1 and 2.)

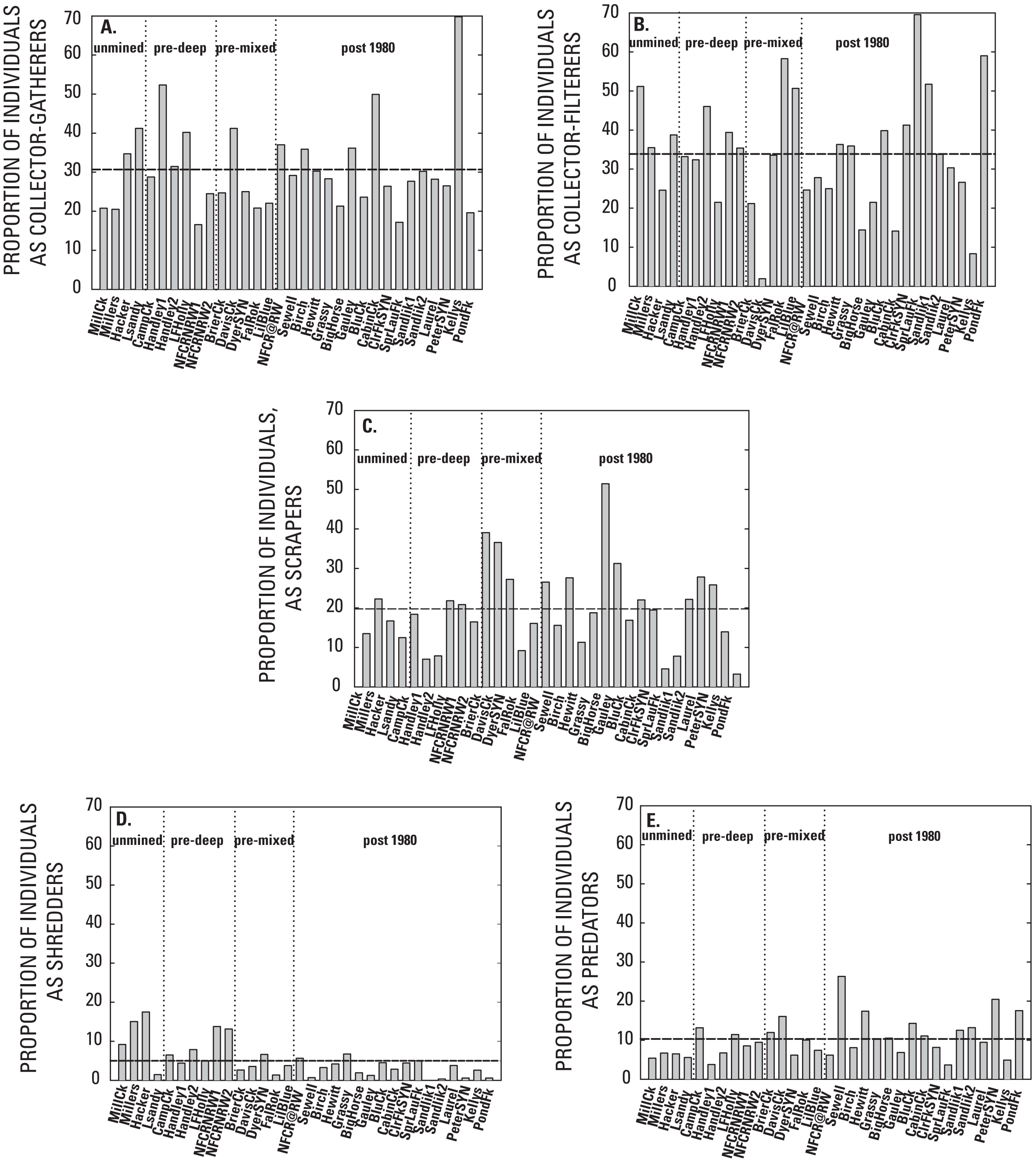

Figure 7 a-e. Proportional representation of (A.) collector-gatherers, (B.) collector-filterers, (C.) scrapers, (D.) shredders, and (E.) predators for coal-mining synoptic-survey sites in the Kanawha River Basin. (Dashed lines indicate mean representation for all sites. Sites are grouped on the basis of mining history and represented as unmined; pre-deep, only deep mined before 1980; pre-mixed, both deep and surface mined before 1980; post 1980, both deep and surface mined before and since 1980. Full names of sites are given in tables 1 and 2.)

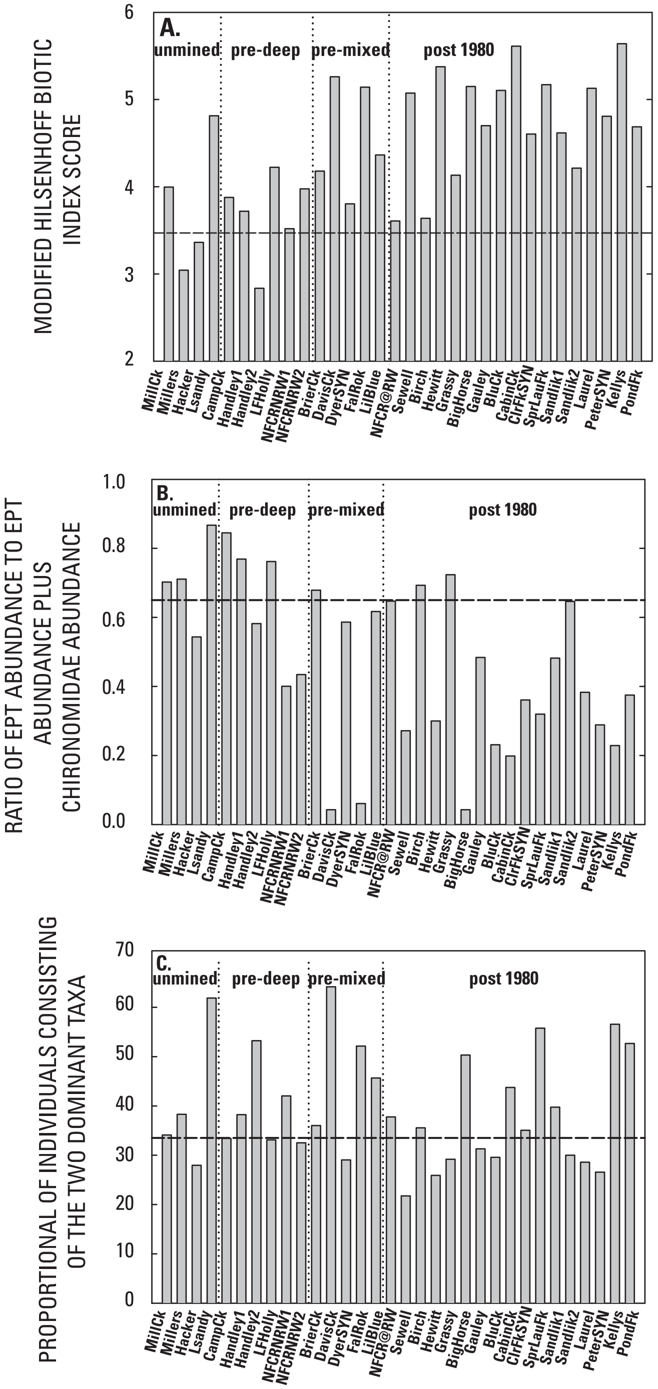

Figure 8 a-c. Pollution tolerance metric values for (A.) Modified Hilsenhoff Biotic Index, (B.) ratio of proportion of EPT to proportion of Chironomidae and EPT, (C.) proportion of individuals consisting of the two dominant taxa for coal-mining region synoptic-survey sites in the Kanawha River Basin. (Dashed lines indicate mean metric values for reference sites--Mill Creek at Hopewell, Millers Creek at Nallen, and Laurel Fork at Hacker Valley. Sites are grouped on the basis of mining history: unmined; pre-deep, only deep mined before 1980; pre-mixed, both deep mined and surface mined before 1980; post 1980, both deep and surface mined before and since 1980. Full names of sites given in tables 1 and 2.)

EFFECTS OF SELECTED ENVIRONMENTAL FACTORS

Differences in invertebrate-community characteristics, such as those reflected in metrics, result from differences in environment factors in the streams, but it is often difficult to determine which environmental factors most strongly affect community structure. Complex interactions of geology, topography, climate and land use do not equally shape invertebrate communities at all sites, but form a gradient from low effect to high effect. Using multivariate techniques of gradient analysis, we identified important environmental factors affecting invertebrate communities in our two data sets, the fixed-site data and the coal-mining synoptic data.

Basin size and physiography most strongly affected community composition in a comparison of fixed-site network samples. Coal mining, and basin attributes related to mining, most strongly affected community composition within the coal-mining region of the Kanawha River Basin. Similarity among fixed-sites was more a factor of basin size and physiography than any land-use pattern. Basin size ranged from about 40 mi^2 to nearly 12,000 mi^2. In contrast, coal-mining synoptic sites largely varied along a gradient of land-use attributes, primarily coal production and water-chemistry and habitat characteristics related to coal mining.

Environmental Influences upon Communities at Fixed Sites

The fixed-site network study design stratified sites by environmental setting, covering a wide range of drainage area, physiography, and land use (table 1), so we expected significant differences among these sites. TWINSPAN analysis was used to classify the fixed-site samples and we inferred significant environmental differences among the resulting groups. This data set of May-June samples from the fixed-site network was edited and censored in the same manner as that described for the classification of indicator and synoptic sites.

At the first division, TWINSPAN separates Kanawha River at Winfield from all other sites (fig. 9). At Winfield, the Kanawha River lacks riffle habitat altogether, and samples were collected from depositional areas along the channel margins. The sample consisted of two taxa, tubificid worms, which were the indicator taxa used in the division, and larvae of the chironomid genus *Tribelos*. The separation of this sample reflects not only the differences between the Winfield site's environmental setting and the environmental setting of all other sites, but also reflects the habitat sampled and the sampling method used.

The next level of division separated the four Williams River at Dyer samples, Peters Creek near Lockwood, and Second Creek near Second Creek from the remaining sites, largely on the basis of the presence of the stonefly genera *Leuctra* and *Acroneuria* and the dragonfly genus *Ophiogomphus*. These sites are all in the northeastern portion of the Kanawha River Basin in the Appalachian Plateaus, and are in basins with drainage areas less than 130 mi^2. Using the ephemerellid mayfly *Drunella* spp. as an indicator, TWINSPAN further separated these sites into two groups; the group in which *Drunella* spp. was present consisted of the Williams River at Dyer samples, and Peters and Second Creeks are grouped where the indicator was absent. The Williams River at Dyer site, our reference condition, has minimal anthropogenic influences with nearly 97 percent of the basin in forest cover and less than 2.25 percent of the basin area in agricultural uses (table 1). Second Creek and Peters Creek samples differed in the presence of nematode worms in the Peters Creek sample, while their basins differed mainly in surficial geology. Peters Creek is in a noncarbonate setting and is a heavily mined basin, but Second Creek drains mostly carbonate rock with no economically important coal reserves in the basin. These two basins also differed in the amount of land used for agriculture — about 7 percent in the Peters Creek Basin and 25 percent in the Second Creek Basin.

Further division of the group of samples that did not contain *Leuctra*, *Acroneuria*, and *Ophiogomphus*, initially resulted in two more groups, one consisting of the four Clear Fork at Whitesville samples, which did not contain the elmid beetle genus *Stenelmis*, and another group where *Stenelmis* was found. This group consisted of the Kanawha River at Kanawha Falls, the New River sites at Thurmond and Glen Lyn, the Reed Creek samples, Bluestone River, and Little River. The Clear Fork site differed from the others in several significant aspects; primarily, the drainage area of the Clear Fork site (63.7 mi^2) is considerably smaller than the other basins, which ranged from 247 to 8,371 mi^2. The Clear Fork Basin also held the highest proportion of quarries, strip mines, and gravel pits of any of the fixed sites (2.27 percent), and was the only basin in this division entirely within the Appalachian Plateaus.

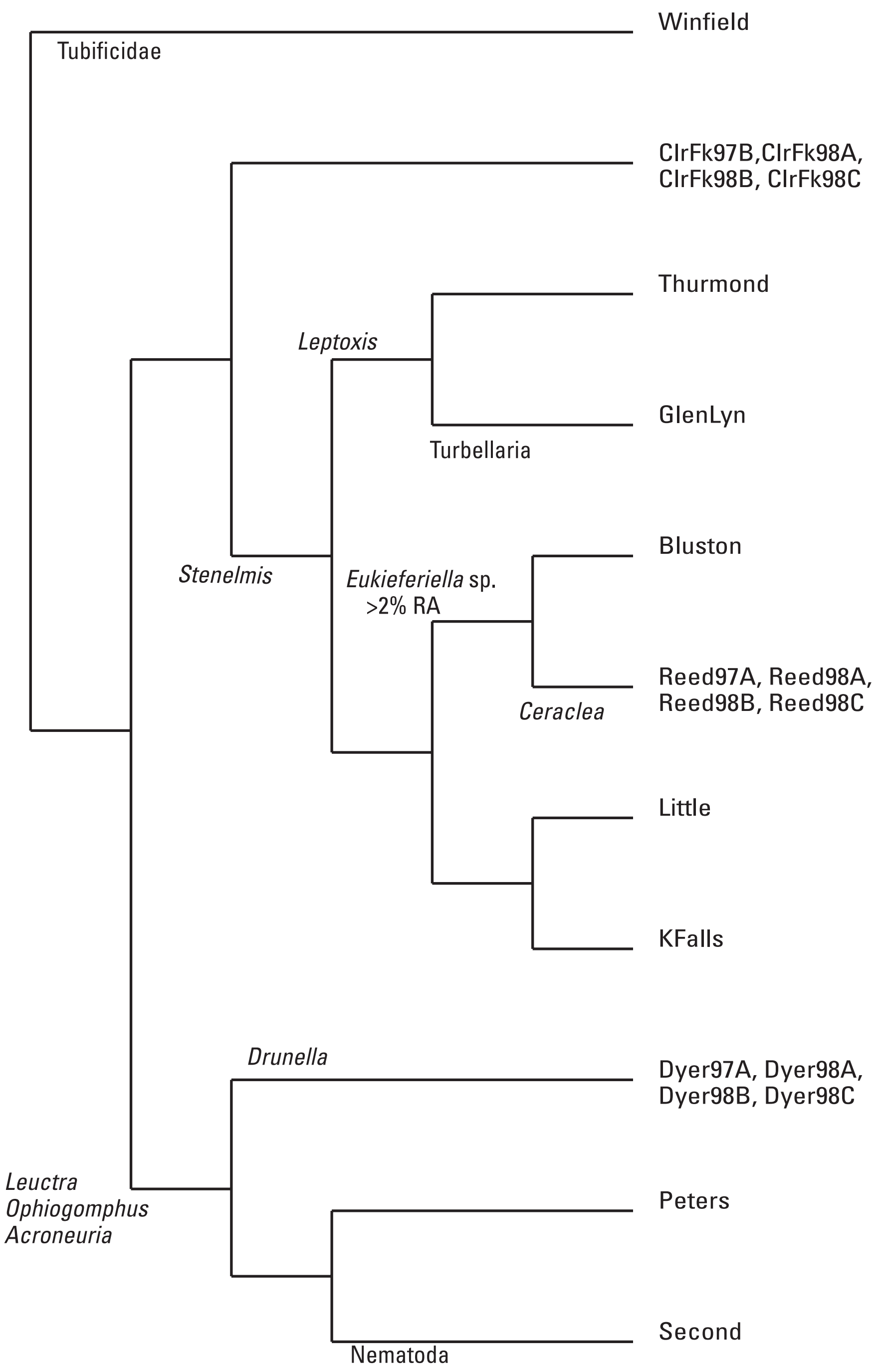

Figure 9. Hierarchical classification, using TWINSPAN, of basic fixed sites in the Kanawha River Basin. (TWINSPAN, Two-Way INdicator SPecies ANalysis; RA, relative abundance; taxa important in assigning sites to groups are listed at that branch of the dendrogram. Full names of sites given in tables 1 and 2.)

The large stream basins separated into a group of New River main stem sites where the snail *Leptoxis* was present, and a group of tributary streams and the Kanawha Falls site where *Leptoxis* was not found. It is not surprising that these sixth-order New River main stem sites, whose faunas differ in the presence of Turbellarian flatworms at Glen Lyn, should group together. TWINSPAN divided the group consisting of tributary sites and the Kanawha Falls site into two smaller groups—Reed Creek and Bluestone River, and Little River and Kanawha Falls. Invertebrate communities in these groups differed by the presence of larvae of the chironomid *Eukiefferiella*, which was present in greater than 2 percent of the total abundance of samples from Reed Creek and Bluestone River, but was not present in the Little River and Kanawha Falls samples. Reed Creek and Bluestone River are similarly sized streams, 247 and 199 mi^2, respectively, and drain basins either entirely or mainly within the Valley and Ridge Physiographic Province. The Little River and Kanawha Falls sites apparently have little in common, and may be grouped only because they are more similar to one another than they are to any other sample.

Results of TWINSPAN analysis of the fixed-site network indicate that geographical influences, such as physiography and basin drainage area, control invertebrate community structure. Discerning other factors or sources of disturbance through comparison of sites would be difficult, given the disparate nature of the fixed sites. These results do not strongly support all of our original hypotheses regarding similarities among sites. We expected sites with similar land-use patterns, such as coal mining at Clear Fork and Peters Creek, or agriculture in carbonate geology at Reed and Second Creeks, to harbor similar invertebrate communities. These expectations were not borne out in this analysis, possibly due to the overriding influences of basin size and physiography. We also expected the New River sites at Glen Lyn and Thurmond to be similar because carbonate water sources, from the Valley and Ridge at Glen Lyn and from the Greenbrier River above Thurmond, were expected to affect communities in similar ways.

Environmental Influences upon Communities in the Coal-Mining Region of the Kanawha River Basin

Indirect and direct gradient-analysis approaches were used to investigate the influence of environmental characteristics upon community structure in the coal-mining region of the Kanawha River Basin. Indirect gradient analysis groups sites on the basis of species composition alone; therefore, researchers must infer environmental gradients from the patterns seen in site and species groupings (Gauch, 1982). Direct gradient analysis uses both species and environmental data to detect patterns in species distribution and the influence of environmental gradients deemed important beforehand by the researcher (Gauch, 1982). TWINSPAN and detrended correspondence analysis (DCA) were used for indirect gradient analysis; canonical correspondence analysis (CCA) was used for direct gradient analysis of environment-community interactions.

Coal production, streamwater specific conductance, sulfate concentrations, and streambed-particle-size distribution most strongly affect benthic invertebrate community structure, according to our analyses. Classification of synoptic sites on the basis of species composition and abundance resulted in two groups differing in the degree of impairment, as determined by comparison of metrics. Coal production, specific conductance, and sulfate concentrations were all higher and median streambed particle size lower in the more impaired basins. Direct gradient analysis using CCA indicates a replacement of pollution-sensitive taxa with pollution-tolerant taxa over a gradient of increasing coal production, specific conductance, and sulfate concentrations and decreasing median streambed-particle size.

Similarities among Benthic Invertebrate Communities in the Coal-Mining Region of the Kanawha River Basin

By comparing species composition and abundance, TWINSPAN and DCA divide the 29 synoptic sites into two groups that differ largely in intensity of coal mining and environmental attributes related to mining. Attributes of the two groups were compared using Tukey’s honestly significant difference test in the computer program, SYSTAT 8.0 (Wilkinson, 1998). Basins in these two groups differed significantly in median coal production, defined as thousands of tons produced per square mile from 1980-1995 ($P=0.012$), and percentage of basin area disturbed by mines, quarries and gravel pits (P=0.017). Invertebrate community composition and metrics also differed between the two groups. Indicator species identified by TWINSPAN and metric values for the group with greater mining intensity reflect greater impairment, whereas indicator species and metric values for the group with little mining activity reflect lesser impairment. The less impaired group of sites was also significantly lower in mining-related attributes such as specific conductance (P=0.004), sulfate concentration (P=<0.001), and alkalinity (P=0.002). Furthermore, the less impaired basins had better habitat, as evidenced by significantly larger median streambed-particle sizes (P=<0.001).

The first TWINSPAN division separates sites on the basis of the presence of the indicator taxa *Epeorus* spp. in greater than 2 percent relative abundance, *Dolophilodes* spp., and *Rhyacophila* spp. (fig. 10). These taxa are generally intolerant of environmental degradation, and both *Dolophilodes* spp. and *Epeorus* spp. are more specifically intolerant to accumulations of fine-grained sediments (Malas and Wallace, 1977, Gurtz and Wallace, 1984, Minshall, 1967). TWINSPAN further separates each of these initial divisions, Group 1, with lower coal production and lower percentages of basin disturbed by mines, is marked by the presence of the indicator species, and Group 2, with more coal production and disturbance, is marked by their absence, into smaller groups.

In Group 1, TWINSPAN first separates the two replicate samples from North Fork of the Cherry River near Richwood on the basis of the absence of the Baetid mayfly genus *Acentrella* (Group 1A). The remaining Group 1 sites are divided by the presence of the Leptophlebdiidae mayfly genus *Paraleptophlebia* in a group of five (Group 1B), and are divided by the presence of Megadrile Oligochaete worms in another group of six (Group 1C). All three sites that were used as a reference condition in the comparison of coal-mining sites were in Group 1, Millers Creek and Laurel Fork at Hacker Valley in Group 1B and Mill Creek in Group 1C. The classification of reference-condition sites in two separate groups can be explained by Millers Creek and Laurel Fork differing from Mill Creek not only in basin size but degree of anthropogenic disturbance as well (higher in Mill Creek Basin).

Sites in Group 2 are first separated on the basis of whether baetid mayflies in the genus *Baetis* were present. No *Baetis* spp. were found in samples from Big Horse Creek at Altman or Davis Creek at Trace Fork (Group 2C). Of the sites where *Baetis* was present, TWINSPAN formed two groups. The first, where heptageniid *Stenonema* mayflies made up over 2 percent of the samples and nematode worms were found, consisted of five sites (Group 2A). The other group, characterized by *Baetis* spp. as more than 5 percent of samples and the *Cricotopus bicinctus* chironomid midge group making up more than 2 percent of samples, consisted of ten sites (Group 2B).

A second analytical technique grouped the sites in much the same pattern as TWINSPAN. We used detrended correspondence analysis (DCA), an ordination technique for species-abundance data, to identify sites with similar community composition (Hill, 1979). By examining groupings of sites and species associations, we indirectly inferred environmental gradients controlling species distribution. Relative-abundance data were octave transformed (Gauch 1982) before ordination. The DCA results largely agree with the results of the TWINPSAN analysis (fig. 11). Most of the groups identified by TWINSPAN are visible in the DCA plot. There are, however, some differences. Notably, TWINSPAN grouped the two North Fork Cherry River near Richwood replicates (Group 1A) separate from all other Group 1 samples, but DCA clusters these samples with Group 1B samples. Other differences consist mainly of group outliers, such as Birch River, a Group 1B site, clustering with Group 1C sites. The DCA results generally confirm the TWINSPAN results, supporting use of TWINSPAN groupings.

The first TWINSPAN division is significant because it divides sites along a gradient of mining intensity, as measured by thousands of tons of coal production per square mile of basin from 1980-1995. The dichotomy between the two groups of sites is stark. Invertebrate-community impairment, indicated by metric values, was significantly lower in Group 1, sites where intolerant indicator taxa were found, than in Group 2. Group 1 also differed significantly from Group 2 in other respects as well. It had a lower intensity of coal mining, as quantified by coal production per square mile, and fewer mining-induced changes in streamwater chemistry. Group 1 also had land-use and physical-habitat characteristics attributable to coal mining or other landscape-scale disturbances. These two groups do not differ significantly in most land-cover characteristics such as proportions of agriculture, forested lands, or residential land uses. Groups 1 and 2 do, however, differ significantly in elevation; most of the Group 1 sites are in the higher Allegheny section of the Appalachian Plateaus. Within Groups 1 and 2, few differences exist

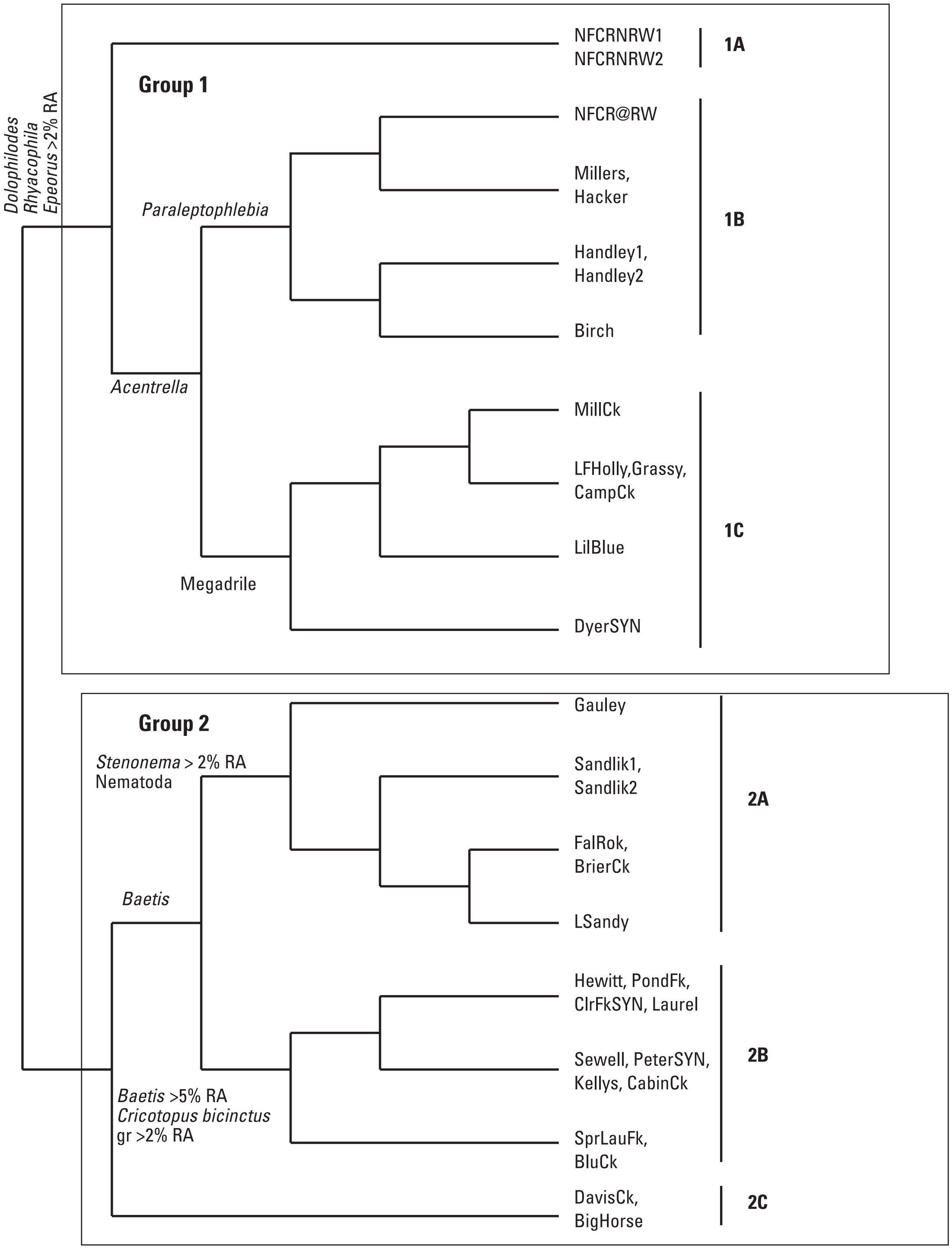

Figure 10. Hierarchical classification, using TWINSPAN, of coal-mining synoptic-survey sites in the Kanawha River Basin. (TWINSPAN, Two-Way INdicator SPecies ANalysis; RA, relative abundance; taxa important in assigning sites to groups are listed at that branch of the dendrogram.)

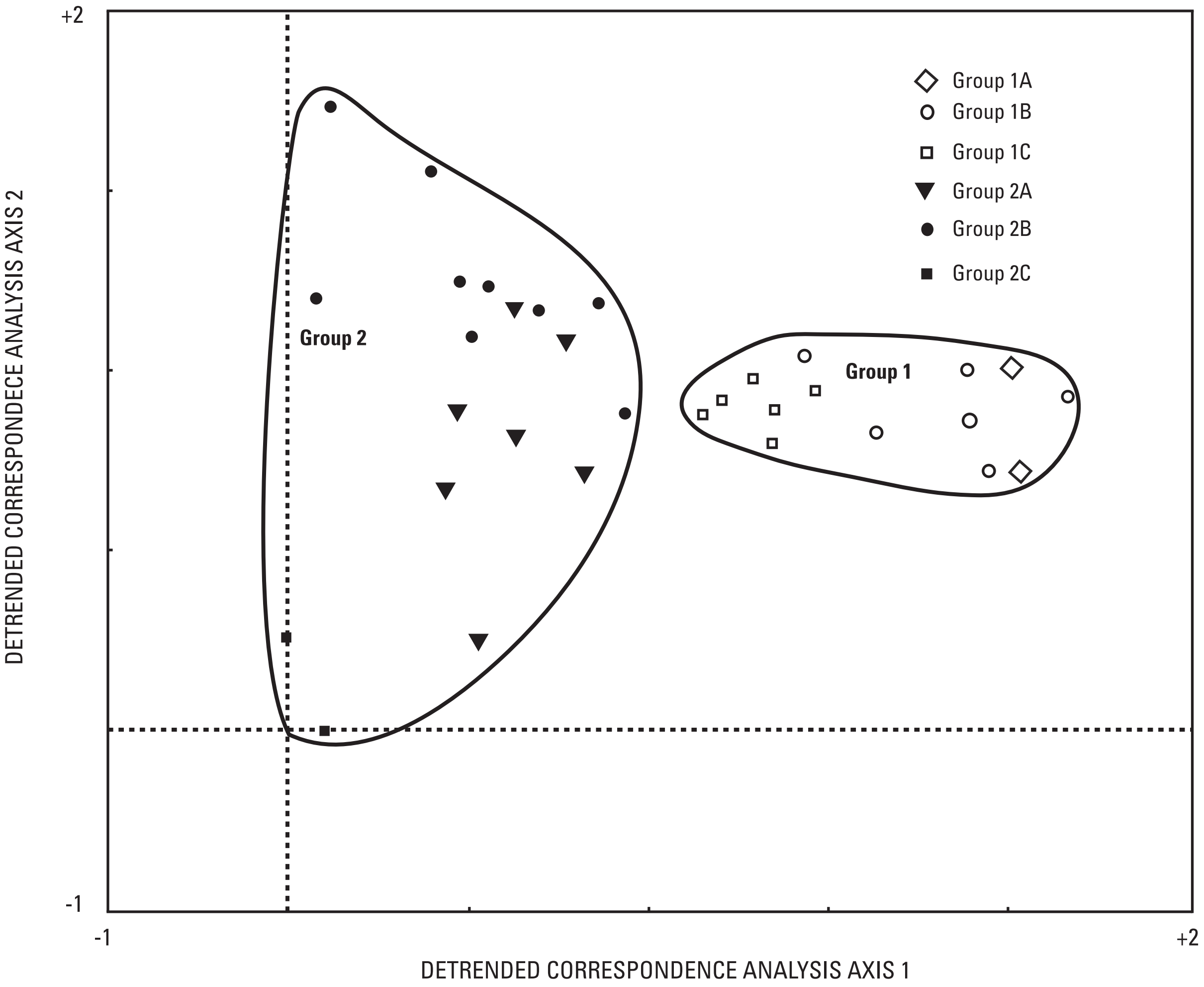

Figure 11. Detrended correspondence analysis plot of axis scores for first two axes for species data from coal-mining synoptic-survey sites in the Kanawha River Basin. (Groups corresponding to those indentified by TWINSPAN analysis are circled.)

There are some exceptions, however, as Group 1C showed slightly higher levels of impairment than either 1A or 1B. This group also had slightly higher levels of several anthropogenic disturbances, including both mining and agriculture. Metric values for Group 2C, consisting of two sites with very poor habitat, indicated greater levels of impairment than the rest of Group 2.

Comparison of Benthic Invertebrate Group Attributes in the Coal-Mining Region of the Kanawha River Basin

Groups 1 and 2 differed significantly in several metrics (fig. 12 a-e), all indicating lower levels of community impairment in Group 1. Taxa richness, number of EPT taxa, proportion of EPT taxa, and ratio of abundance of EPT taxa to abundance of chironomid taxa plus abundance of EPT taxa—low values of which indicate environmental degradation—were all significantly higher in Group 1. Group 2 values of the modified Hilsenhoff Biotic Index and proportion of Chironomidae were significantly higher than Group 1, both metrics indicating increased representation of tolerant taxa. Percent representation of dominant taxa and proportion of functional feeding groups (with the exception of shredder taxa) did not differ significantly between the groups.

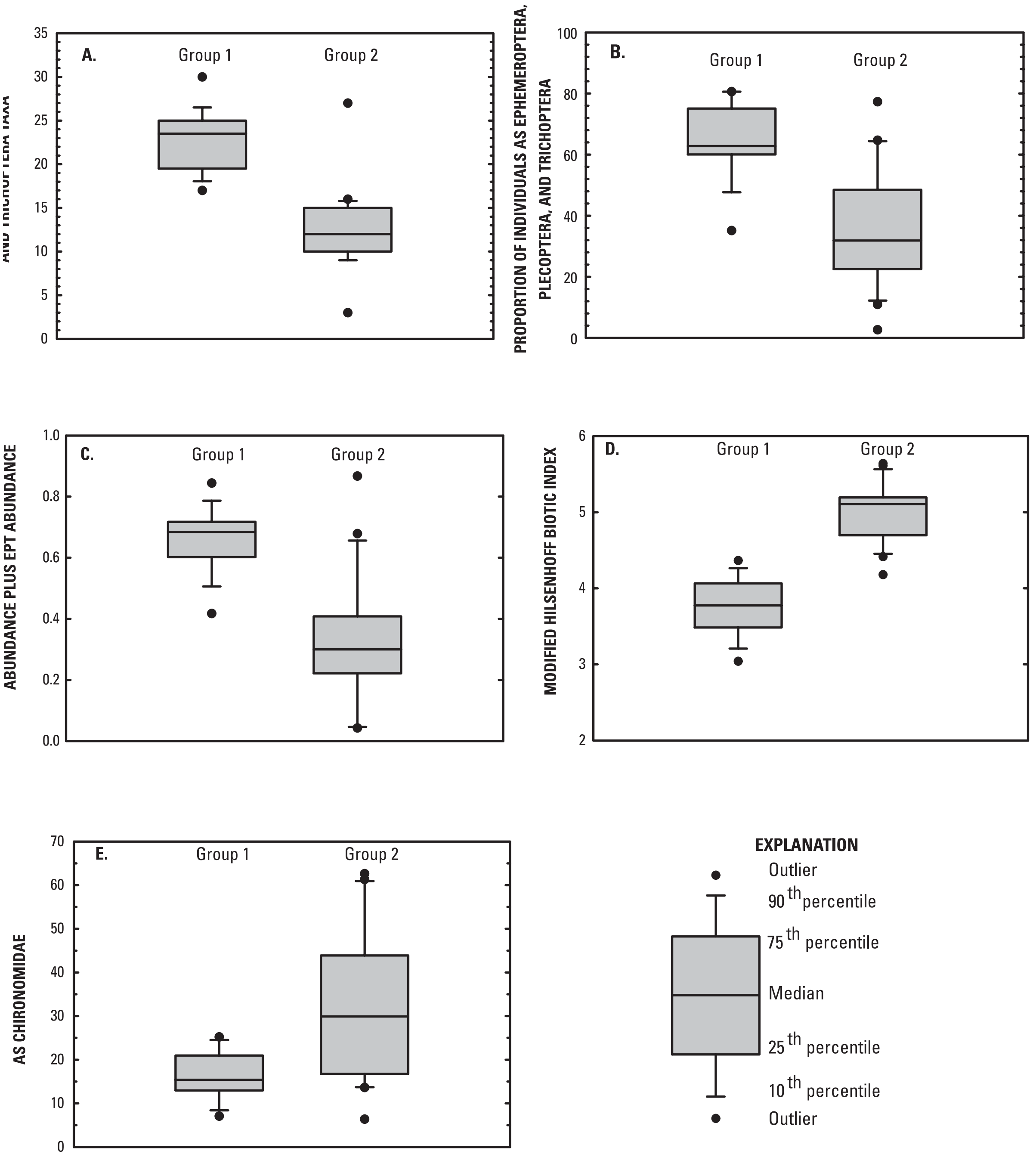

Figure 12 a-e. Comparison of metric values for Groups 1 and 2 of the TWINSPAN classification showing (A.) number of Emphemeroptera and Trichoptera taxa, (B.) proportion of individuals as Ephemeroptera, Plecoptera, and Trichoptera, (C.) ratio of EPT abundance to EPT abundance plus Chironomidae abundance, (D.) Modified Hilsenhoff Biotic Index, and (E.) proportion of individuals as Chironomidae, for coal-mining synoptic-survey sites in the Kanawha River Basin. (EPT, Ephemeroptera, Plecoptera, and Trichoptera)

Chemical and physical stream environments differed significantly between Groups 1 and 2. Although pH did not differ between the two groups, specific conductance, sulfate concentration and alkalinity were all significantly higher in Group 2 (fig. 13 a-d). Streambottom particle distribution, represented by measurement of the intermediate axis of 100 streambed particles randomly selected from transects in one pool and two riffles per reach, also varied between the groups. Median streambed-particle size was smaller in Group 2 (fig. 13 e), indicating increased transport and deposition of fine-grained sediment in basins with greater mining intensity. Each of these differences is associated with coal mining. Sampling sites in Groups 1 and 2 also differed significantly in elevation (fig. 13 f), which is typically correlated with stream temperature, gradient and particle-size distribution.

On the basis of an analysis of MRLC data, land-use characteristics did not vary between groups, except with respect to those characteristics related to coal mining (fig. 14). The two groups did not differ with respect to proportion of agricultural lands, residential areas, transportation, or commercial/industrial land cover. Characteristics of coal mining, such as coal production and percent of land cover as mines, quarries and gravel pits, were significantly higher in Group 2. The maximum identified coal production in Group 1 was 9.2 thousand tons/mi^2, a level exceeded by two thirds of the basins in Group 2. Although seven of the 12 basins in Group 1 were disturbed by mining or quarries, in only two basins did the disturbances exceed 1 percent of basin area. This is in sharp contrast to the eight of 17 basins in Group 2 with more than 1 percent of basin as mined areas or quarries.

According to this analysis, coal mining, more than any other land use, affects the in-stream environment and thereby shapes benthic invertebrate communities in the Kanawha River. Coal mining or any other activity that involves moving significant amounts of earth and rock alters the chemistry and geomorphology of these basins. Values for constituents related to total dissolved solids, such as specific conductance and sulfate concentration, most likely increase above background levels as water percolates through the highly fractured, unconsolidated material that is the result of such activities. Flow through this newly unconsolidated material typically results in higher dissolution and mobilization of minerals in the parent rock than would occur in undisturbed rock, where flow paths along bedding planes left minerals virtually unexposed to water.

The stream’s physical character is affected by the same processes. The fracturing of rock overlying coal seams increases the transport and deposition of finegrained material in the stream reaches. As fine-grained sediment accumulates downstream, it fills the interstitial spaces in the substrate, which reduces the quantity and quality of available habitat for benthic invertebrates.

As in most ecological studies, a combination of influences was found to affect benthic-invertebrate communities. In this study, the chemical and physical habitat are altered by coal mining and other activities that involve moving vast amounts of earth and rock. The number of EPT taxa present in a sample is negatively correlated with sulfate concentration and specific conductance (fig. 15 a-c). It is unknown whether this correlation reflects the effect of increased ionic strength represented by these increases in sulfate and specific conductance, or if these constituents are surrogates for another co-variable. The number of EPT taxa in a sample is positively correlated with median particle size of streambed sediments. Particle-size distribution is an important factor in habitat availability because many intolerant taxa require open interstitial spaces in the substrate. Scores for the HBI responded to increased disturbance in a manner consistent with that for number of EPT taxa. Higher HBI scores, indicating increased impairment, correlated with higher values for sulfate concentration, specific conductance, and median particle size (fig 16 a-c).

Comparison of TWINSPAN first-division groups indicates a higher level of invertebrate-community impairment related to mining and similar activities that increase specific conductances and concentrations of dissolved constituents and decrease median particle sizes. At subsequent levels of division, differences between groups became more subtle. Land-use characteristics of subsequent groups within first-division groups did not significantly differ.

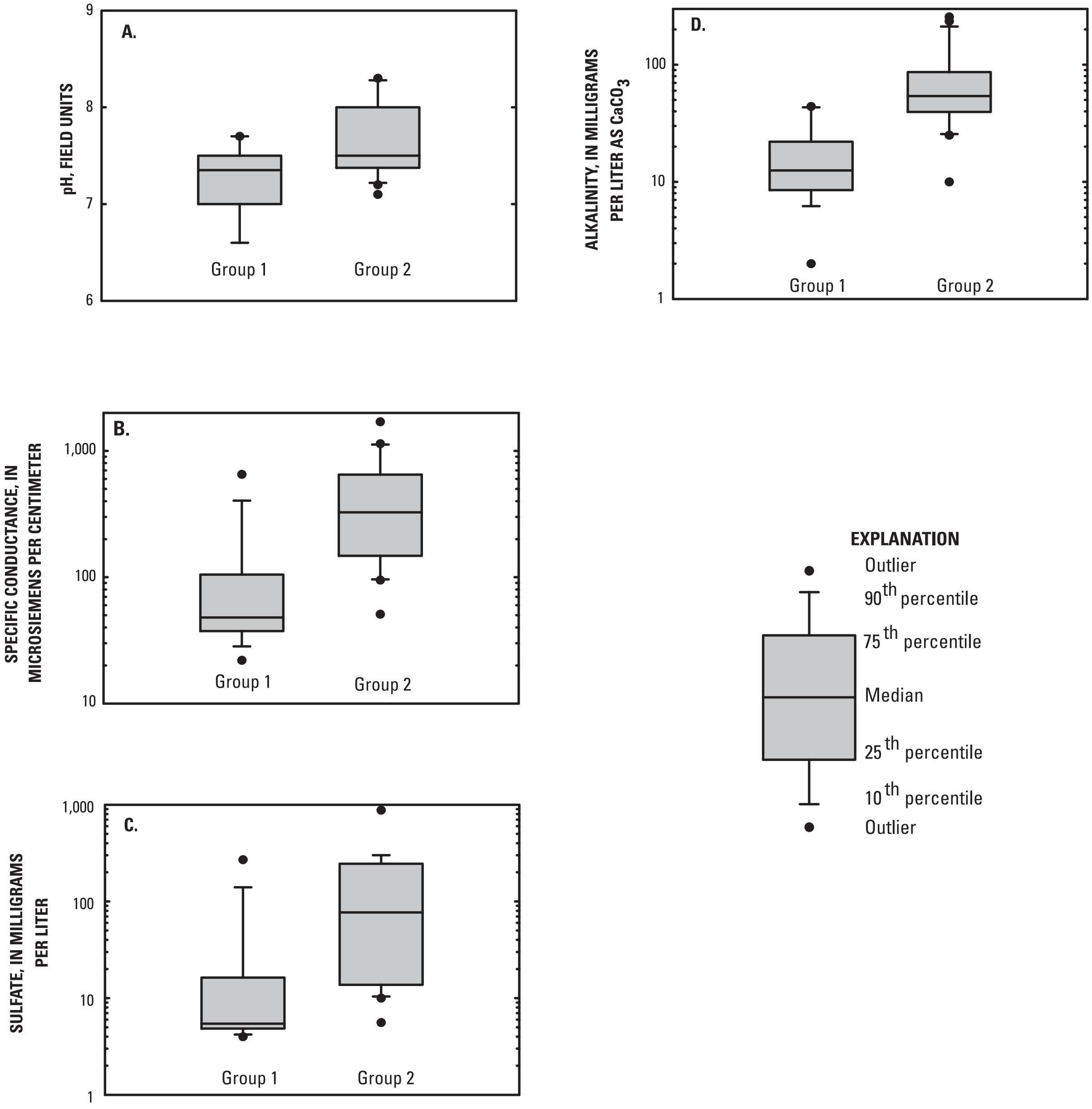

Figure 13 a-d. Comparison of (A.) pH, (B.) specific conductance, (C.) sulfate concentration, and (D.) alkalinity, for TWINSPAN classification groups for coal-mining synoptic-survey sites in the Kanawha River Basin.

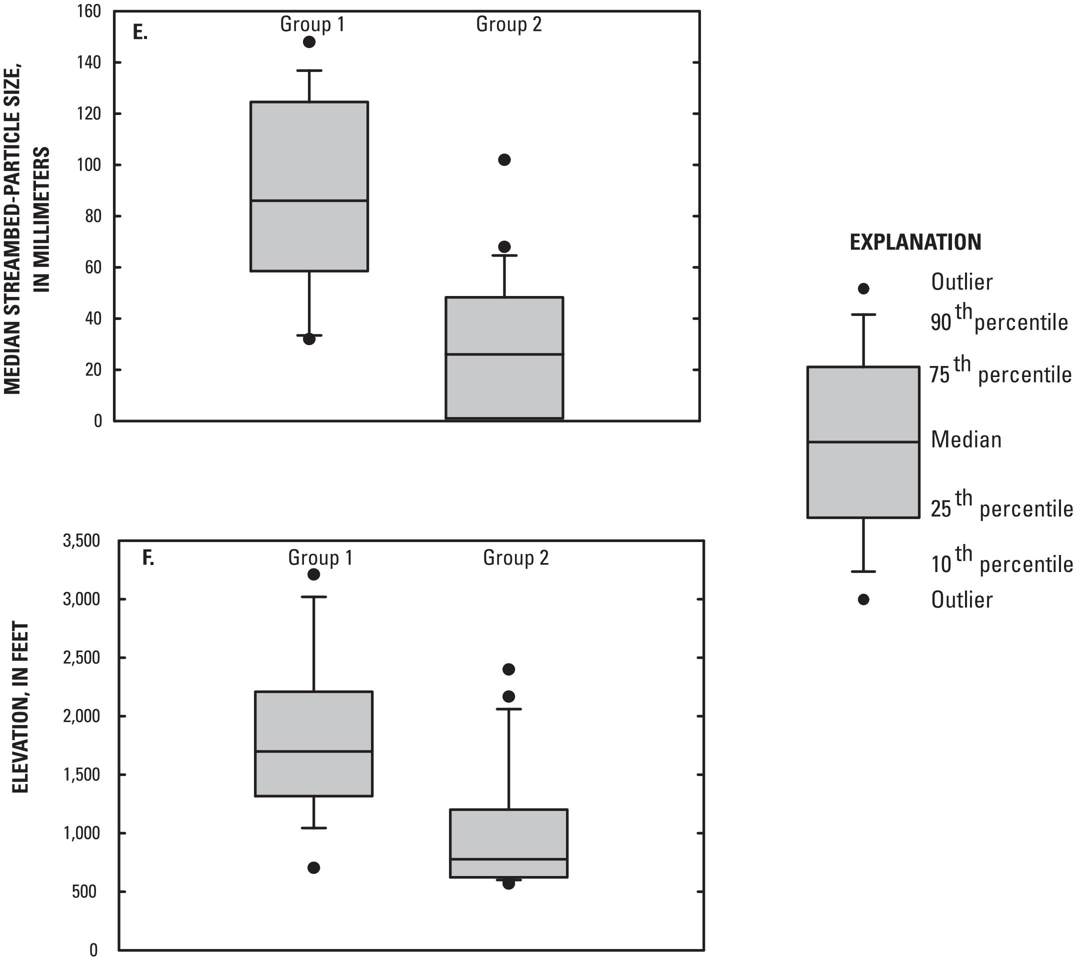

Figure 13 e-f. Comparison of (E.) median streambed-particle size, and (F.) elevation, for TWINSPAN classification groups for coal-mining synoptic-survey sites in the Kanawha River Basin.

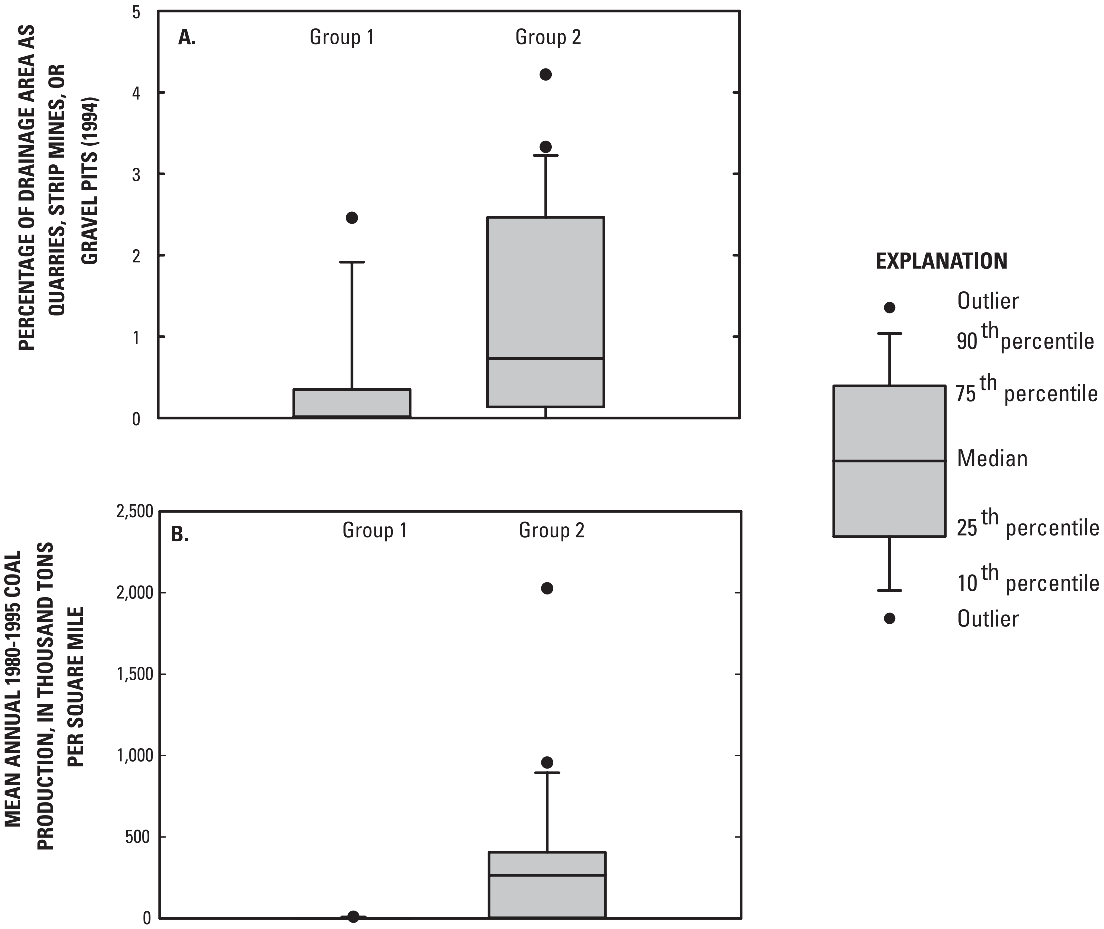

Figure 14 a-b. Coal-mining characteristics showing (A.) percentage of drainage area as quarries, strip mines, or gravel pits, and (B.) mean annual coal production in thousand tons per square mile for TWINSPAN classification groups of coal-mining synoptic-survey sites in the Kanawha River Basin.

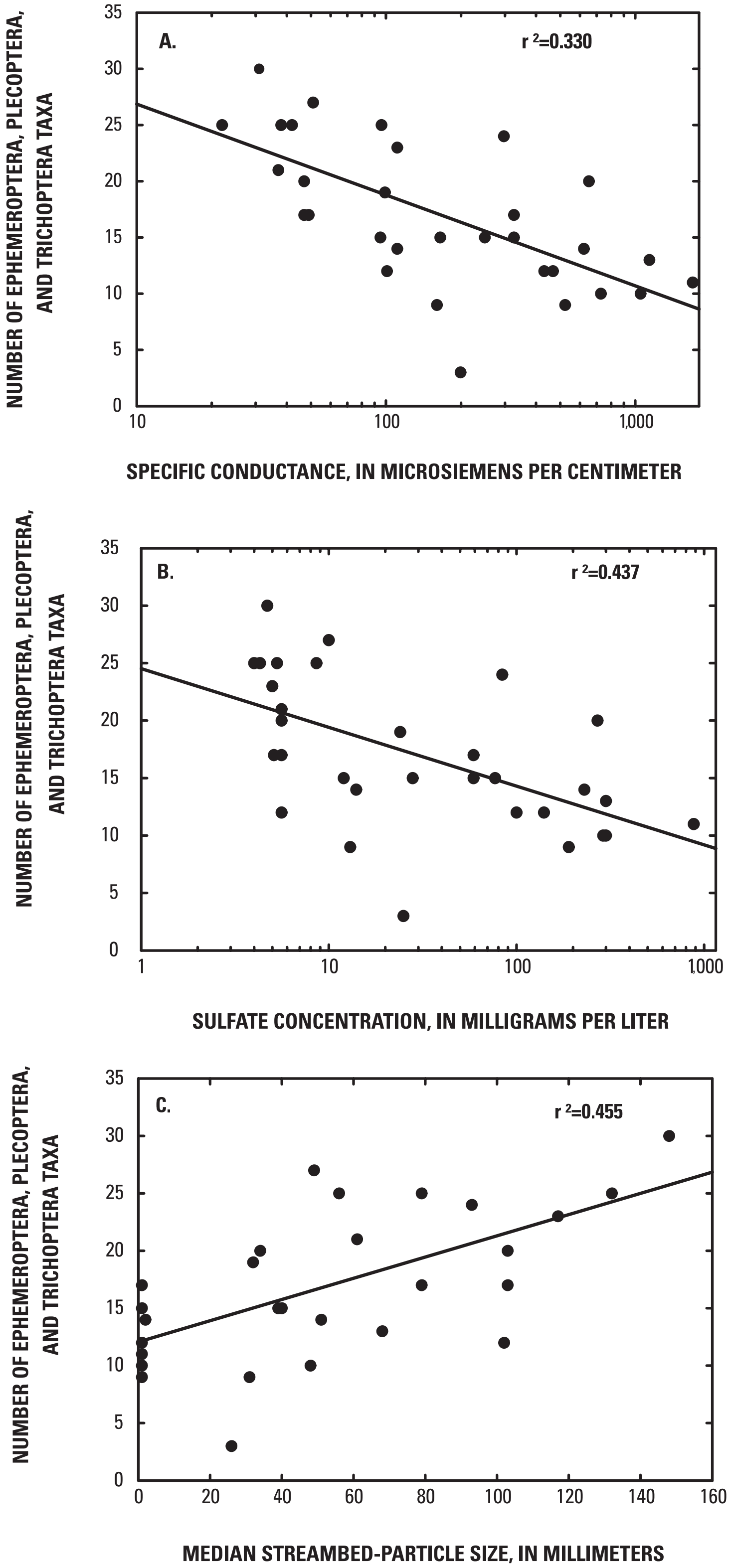

Figure 15 a-c. Relations among EPT taxa numbers with (A.) specific conductance, (B.) sulfate concentration, and (C.) median streambed-particle size for coal-mining synoptic-survey sites in the Kanawha River Basin.

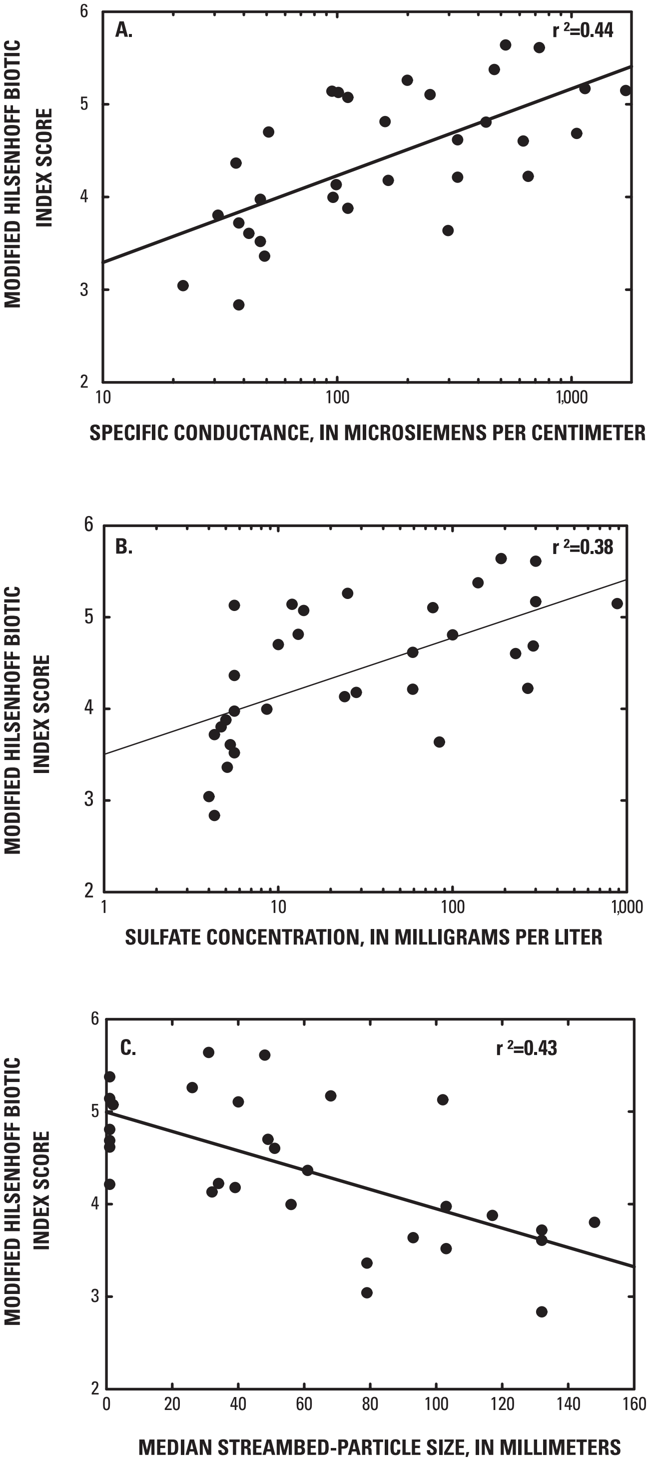

Figure 16 a-c. Relations of modified Hilsenhoff Biotic Index scores with (A.) sulfate concentration, (B.) specific conductance, and (C.) median streambed-particle size for coal-mining synoptic-survey sites in the Kanawha River Basin.

Environmental Gradients Affecting Benthic Invertebrate Communities in the Coal-Mining Region of the Kanawha River Basin

Using the Canoco software package (ter Braak and Smilauer, 1998), we investigated the influence of environmental gradients (chemical concentration, land-use characteristic, or other factor that varies along a gradient from high to low) through canonical correspondence analysis (CCA), a direct gradient analysis ordination technique. CCA is a unimodal model used to relate species data to environmental variables. It linearly combines measured environmental variables into synthetic gradients or axes. These synthetic gradients are calculated so that species scores are maximally dispersed. In other words, each axis is a combination of environmental influences that explains the distribution of species among sites (ter Braak, 1987, ter Braak and Verdonschot, 1995). The CCA results can be plotted with environmental variables, site data, species data, or combinations of the three. As stated, the axes are synthetic combinations of multiple environmental data. Eigenvectors representing the influence of individual environmental variables that comprise the synthetic axes are also plotted. The direction the eigenvector arrows point indicates the “direction of maximum change of the associated variable” and the arrow’s length is proportional to “ the maximum rate of change” (ter Braak and Verdonschot, 1995). The positions of site points relative to environmental variable eigenvectors approximate the influence exerted by the variable upon the site. Furthermore, species points projected onto environmental eigenvectors indicate the weighted average for that species along a gradient of the environmental variable.

For CCA analyses, we used data that had been edited, censored and octave-transformed in the same manner described for TWINSPAN analyses. Initially, we conducted analyses with up to 28 environmental variables possibly affecting invertebrate communities, but focused upon environmental characteristics that differed significantly among the TWINSPAN groups described earlier in this section. Many variables were collinear, in which case we selected the variable exerting the strongest influence upon the ordination and deleted the weaker co-linear variables from the analysis. We continued this series of analyses in an iterative fashion until a stable ordination was reached that explained the greatest proportion of species-environment variability.

As with the earlier analyses, CCA indicates that coal mining’s effects, both chemical and physical, act strongly to shape invertebrate communities in the coal-mining areas of the Kanawha River Basin. The first two axes, consisting of a combination of the median streambed-particle size, tons of coal production per square mile of basin area (1980-1995), specific conductance, sulfate concentration in streamwater, total aluminum concentration in streamwater, and mercury concentration in stream-bottom material, explained 60 percent of the variance of the species-environment relation (fig. 17, table 7). Sites are plotted by their scores on the synthetic axes and species points represent the weighted average of the sites where these species occur. The significant environmental gradients identified through CCA agree with those that significantly differed among TWINSPAN groups, specifically median streambed-particle size, coal production, specific conductance, and sulfate concentration. This analysis also indicated that total aluminum affected communities. Aluminum may be mobilized from sources near acidic mine drainages, then precipitate when these waters reach streams with excess acid neutralizing capacity. Mercury concentration in stream-bottom material also appears to significantly affect communities, although this is likely a surrogate variable for an effect of higher precipitation and atmospheric deposition of mercury that occurs in the Allegheny Highlands section of the Appalachian Plateaus, where mercury concentrations in sediment were highest (Messinger and Hughes, 2000).

Table 7. Canonical correspondence analysis axis eigenvectors and environmental variable axis loadings for an ordination of samples from coal-mining synoptic-survey sites in the Kanawha River Basin

	Axis 1	**Axis 2**
Eigenvalue	0.2402	0.1059
Environmental Factor	**Environmental Factor Loading**	
Specific conductance	0.7556	0.1123
Sulfate concentration in streamwater	0.6972	0.0267
Total aluminum in streamwater	0.0558	-0.3494
1980-1995 coal production per square mile of basin area	0.5117	0.6303
Median streambed-particle size	-0.8366	-0.0016
Mercury concentration in streambed sediment	-0.2648	-0.2959

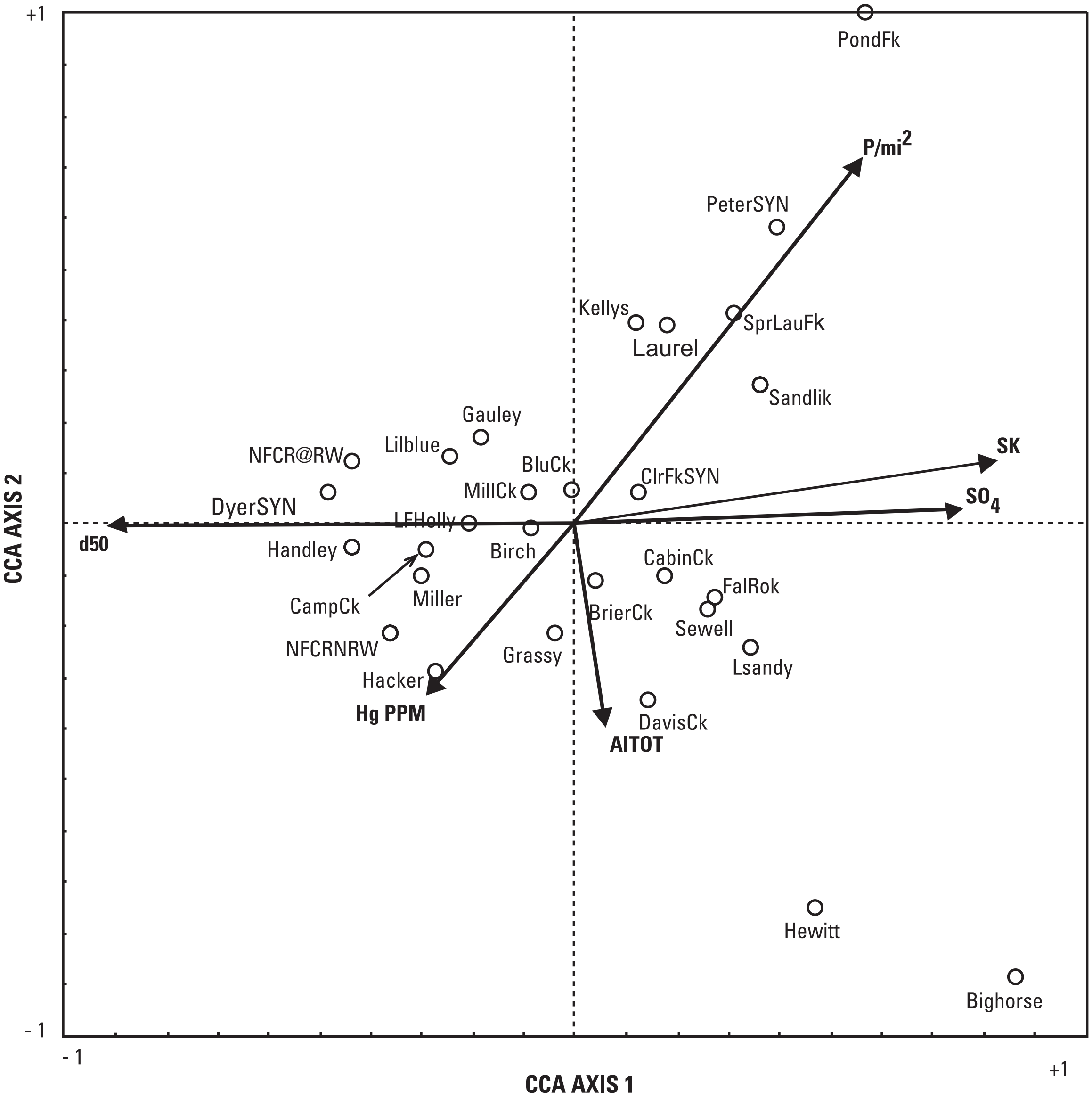

Figure 17. Site scores and environmental variable eigenvector biplot of first two axes for canonical correspondence analysis (CCA) of data from coal-mining synoptic-survey sites in the Kanawha River Basin. Site points represent weighted averages of environmental variables. Eigenvectors (arrows) represent the direction of maximum change of that environmental variable. Site data are listed in table 2. (**AlTOT**, total aluminum concentration, in micrograms per liter; **Hg PPM**, mercury in streambed sediment in parts per million; **P/mi^2**, mean annual 1980-1995 coal production, in thousand tons per square mile of basin area; **d50**, median streambed-particle size, in millimeters; **SK,** specific conductance, in microSiemens per centimeter; **SO$_4$**, sulfate concentration, in milligrams per liter.)

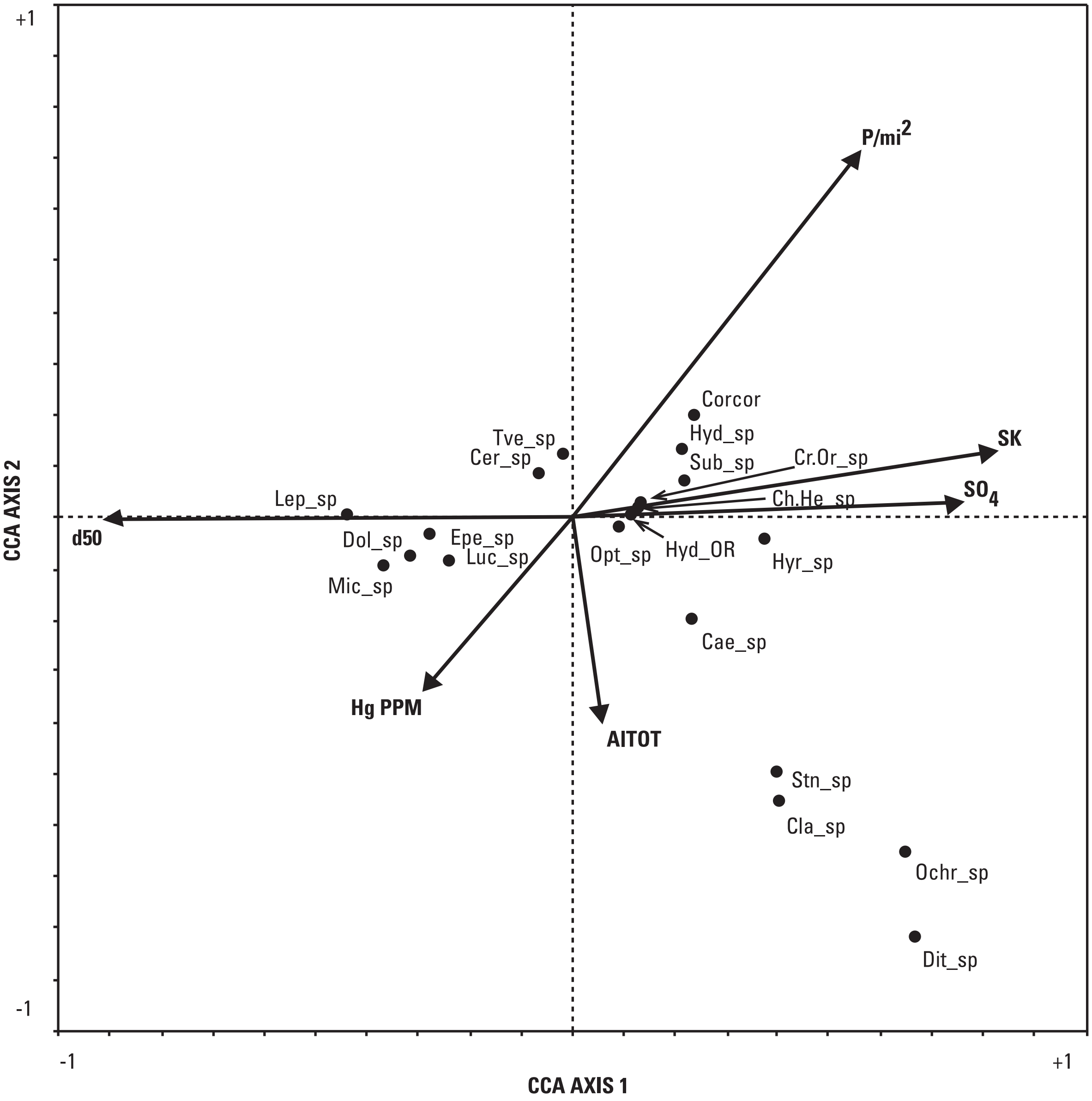

Figure 18. Taxon scores and environmental variable eigenvector biplot of first two axes of canonical correspondence analysis (CCA) of data from coal-mining synoptic-survey sites in the Kanawha River Basin. Taxon points represent weighted averages of species abundances among site points shown in figure 17. Only taxa with low variance from the species centroid (goodness of fit values exceeding 20) are shown. Eigenvectors (arrows) represent the direction of maximum change of that environmental variable. Taxa data are listed in table 6. (**AITOT**, total aluminum concentration, in micrograms per liter; **Hg PPM**, mercury in streambed sediment in parts per million; **P/mi^2**, mean annual 1980-1995 coal production, in thousand tons per square mile of basin area; **d50**, median streambed-particle size, in millimeters; **SK,** specific conductance, in microSiemens per centimeter; **SO$_4$**, sulfate concentration, in milligrams per liter.)

The gradients identified through CCA affect invertebrate distribution in a pattern similar to that identified by TWINSPAN analysis (fig. 18). The mayfly genus *Epeorus* and the caddisfly genus *Dolophilodes,* indicator species in the first division of sites in the TWINSPAN analysis, show a strong preference for larger median particle sizes. This analysis more clearly links species response to the environmental characteristics that comparison of TWINSPAN groups suggested was important. Several taxa dominated sites that scored high along the specific conductance and sulfate concentration eigenvectors and low on the median particle size eigenvectors, sites mainly in basins that were mined before 1980, but not since. Among these taxa were the midges *Cladotanytarsus* and *Dicrotendipes,* the elmid beetle *Stenelmis,* and the hydroptilid caddisfly genus *Ochrotrichia.* No taxa were strongly associated with the coal-production eigenvector, although the hellgrammite *Corydalus cornutus* and *Hydropsyche* caddisflies were commonly found at high production sites.

Direct gradient analysis of benthic-invertebrate communities in the coal-mining region of the Kanawha River Basin yielded results similar to those of the indirect gradient analysis, namely that median particle size, specific conductance, and sulfate concentrations strongly affect these communities. Furthermore, these factors were affected, in part, by the intensity of coal mining in the basin. Direct gradient analysis through CCA also indicated total aluminum concentrations and mercury concentrations in stream-bottom material as having roles in structuring invertebrate communities.

SUMMARY AND CONCLUSIONS

Analysis of invertebrate communities and environmental factors in the Kanawha River Basin indicates that the effects of coal mining, such as changes in streamwater chemistry and benthic habitat quality, strongly shape those communities. Although basin size and physiography were also important in structuring communities, coal mining was the greatest anthropogenic influence in basins of less than 128 mi^2. Other major land uses in the basin included low-intensity agriculture and low densities of rural residences, but these uses did not affect communities to the extent that coal mining did.

Coal mining, agriculture and rural residential land-use patterns all resulted in benthic invertebrate communities that were impaired relative to reference conditions. Agricultural activities in the Kanawha River Basin, primarily pasturage and hay cultivation, minimally affected communities. Metric values in basins where agriculture was the dominant non-forest land use commonly approached and in some cases exceeded the values for the reference condition. Values for basins selected as indicators of coal mining or rural residential land use rarely approached reference conditions.

Coal mining, as indicated by the coal-mining synoptic study, appears to influence upon invertebrate communities in several ways. These include increased habitat degradation and mineralization of surface waters, both of which are most noticeable in areas of high coal production and extensive surface mining. Specifically, median particle size of streambed material, and the specific conductance and sulfate concentration of streamwater most strongly affected invertebrate communities in the coal-mining region of the Kanawha River Basin, and these physical and chemical characteristics were related to mining intensity. Conspicuously absent from the coalfields of the Kanawha River Basin is the classic acidic mine drainage often seen as the greatest source of environmental damage related to mining. This general absence is largely due to the relatively high alkalinity of the calcareous shales in this region, but also to treatment of acidic mine drainage required by regulation.

The increased mineralization of surface waters in extensively mined basins of the Kanawha River Basin, as indicated by elevated specific conductances and concentrations of sulfate relative to basins with little or no coal production, is related to a lesser representation of sensitive taxa in the communities. The mineralization of surface waters most likely occurs both as a result of mine drainage from deep mines and from percolation of runoff through the unconsolidated rock of valley fills. The valley-fill material is chemically similar to the surrounding rock, but altered flow paths and a much higher porosity allows for increased water contact and dissolution of minerals present in the fill that would not have been exposed to water in the parent material. Although increased sulfate concentrations correlate with loss of sensitive taxa and increases in tolerant taxa as well or better than specific conductance, it is unclear whether sulfate concentration or the overall dissolved solids concentration, as represented by specific conductance, is responsible for these changes in the invertebrate community. Furthermore, it is unclear whether these chemical changes affect communities by altering osmoregulatory efficiency, ion-specific toxicity, or some other mechanism.

The mechanism by which habitat degradation affects an invertebrate community is clear; sensitive taxa are displaced as the habitat they require to complete their life cycle is altered. The decrease in median particle size (d_{50}) of streambed sediment was the habitat characteristic that most strongly correlated to loss of sensitive taxa groups and increases in tolerant taxa. This change in the stream environment was also related to mining intensity; median particle size decreased as coal production per square mile of basin increased. We also noted a decrease in median particle size for basins where landscape level alterations other than surface mining had occurred, such as large construction projects and stream dredging. Investigating the processes by which surface mining changes stream habitat will be important, because it is currently uncertain whether these changes are associated solely with the actual mining process or may also be ramifications of alterations of stream geomorphology. Although it is clear that the surface-mining process itself mobilizes sediments that can enter adjacent streams, it is unclear whether the construction of valley fills alters the geomorphology of stream basins to an extent that would cause channel adjustments resulting in increased bank erosion and streambed instability.

Investigation of the relations among invertebrate communities and environmental variables indicates that coal mining is the most significant cause of impairment to benthic invertebrate communities in streams in the Kanawha River Basin. Coal mining alters both the physical and chemical characteristics of these streams to a degree that, in turn, alters the composition of invertebrate assemblages. The most significant of the coal-mining induced changes are increases in specific conductance and sulfate concentration and decreases in median streambed-particle size. Investigations of the effects of other land-use practices in the Kanawha River Basin, specifically agriculture and rural residential patterns, showed that these land uses minimally affected invertebrate communities, probably because of the low level of intensity at which most farming is conducted within the basin. Communities from the one site used as an indicator of rural residential land use, a mix of dispersed residences, forest and very low intensity agriculture, were moderately impaired.

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