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Fish Communities and Their Relation to Environmental Factors in the Kanawha River Basin, West Virginia, Virginia, and North Carolina, 1997–98

By TERENCE MESSINGER and D.B. CHAMBERS

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Cover photo—An angler fishes a stream in Randolph County, West Virginia. Photo by Stephen Shaluta, West Virginia Division of Tourism.

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

Robert M. Hirsch

CONTENTS

FIGURES

TABLES

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

CONVERSION FACTORS

Multiply	by	to obtain
acre	4,047	square meter
cubic feet per second (ft^3/s)	0.02832	cubic meter per second
cubic feet per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer
fluid ounce	29.57	milliliter (mL)
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
pound (lb)	0.4536	kilogram
square mile (mi^2)	2.590	square kilometer
ton	0.9072	megagram
year (yr)	0.002740	day

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

$$^oF = (1.8 \times {}^oC) + 32$$

$$^oC = ({}^oF - 32) \times 0.5555$$

VERTICAL DATUM

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

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 (µg/L). Milligrams per liter are 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

AC	Alternating current
DC	Direct current
MRLC	Multi-Resolution Land Characteristics
NAWQA	National Water-Quality Assessment Program
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
r	correlation coefficient
SMCRA	Surface Mine Control and Reclamation Act
USEPA	U. S. Environmental Protection Agency
USGS	U. S. Geological Survey
WVDEP	West Virginia Division of Environmental Protection
WVDNR	West Virginia Division of Natural Resources
>	greater than
<	less than

Fish Communities and Their Relation to Environmental Factors in the Kanawha River Basin, West Virginia, Virginia, and North Carolina, 1997–98

By Terence Messinger *and* Douglas B. Chambers

Abstract

Stream size and zoogeography affected species composition and relative abundance of fish communities more than water-quality effects of land uses among the 21 sites sampled in West Virginia and Virginia. Most commonly-used fish metrics based on counts of species were significantly greater in sites downstream from Kanawha Falls (an important barrier to fish movement) than in sites upstream from Kanawha Falls. Commonly used metrics based on proportions of the fish community belonging to trophic or tolerance guilds were not significantly different upstream and downstream from Kanawha Falls. Variance in some widely used fish metrics was greater among multiple reaches sampled within stream segments than among all sites.

Stream size dominated species distribution and site separation along environmental gradients within groups of sites upstream and downstream from Kanawha Falls, according to ordination. Cluster analysis separated the two largest sites from all others, then divided the remaining sites by size and physiography. Similarity of fish species composition, measured using the Jaccard Similarity Coefficient, was less when compared among three contiguous reaches sampled in one stream on consecutive days than among some sites from different streams; within-site similarity decreased with increasing stream size. Cluster analysis grouped all reaches sampled at the same site in the same cluster.

INTRODUCTION

This study, part of the National Water-Quality Assessment (NAWQA) Program, assessed the effects of land uses on water quality using multiple lines of evidence (Gilliom and others, 1995). These lines of evidence included sampling water from streams and wells to determine chemical and microbiological composition, bed sediment and fish tissue from streams to determine chemical contamination, and surveying habitat structure and algal, benthic, and fish-community composition from streams.

Purpose and Scope

This report compares fish communities from selected sites in the Kanawha River Basin and describes the effects of the most important aspects of the chemical and physical environment on fish communities in the Kanawha River Basin. The fish communities discussed were collected in 30 samples from 21 stream sites during 1997–98. Drainage area of sites where fish communities were studied ranged from less than 10 mi^2 to greater than 10,000 mi^2.

Description of the Kanawha River Basin

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

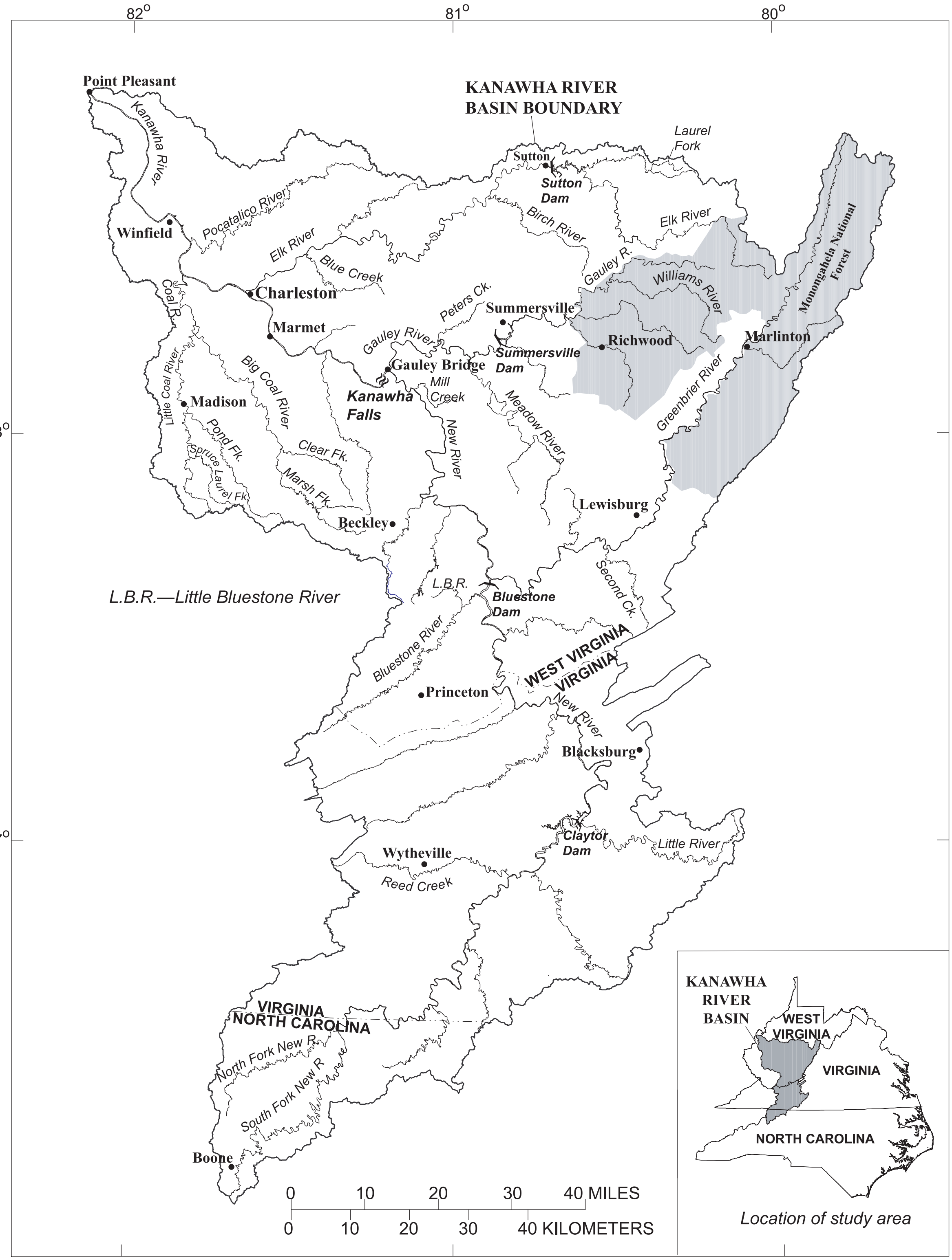
The Kanawha River drains parts of three physiographic provinces (fig. 2), the Blue Ridge Province (17 percent), Valley and Ridge Province (23 percent), and the Appalachian Plateaus Province (60 percent) (Fenneman, 1938). In the Appalachian Plateaus part of the basin, hilltop altitude ranges from about 1,000 ft to about 4,000 ft, generally from northwest to east and southeast, and relief and stream gradient generally are greater in the area with greater altitude. The differences in altitude and relief within the Appalachian Plateaus have caused differences in environmental conditions including precipitation, streamflow, stream gradient, terrestrial vegetation, and land use (Messinger and Hughes, 2000).

The climate of the Kanawha River Basin is classified as continental, with four distinct seasons and marked temperature contrast between summer and winter (Messinger and Hughes, 2000). The maximum precipitation in the basin is greater than 60 in/yr both in the northeastern Appalachian Plateaus and in the southern Blue Ridge Province. The minimum precipitation in the basin, about 36 in/yr, is in the Valley and Ridge Province and in the Greenbrier Valley, in a regional rain shadow; however, the westernmost part of the Appalachian Plateaus receives only slightly more precipitation, about 40–45 in/yr.

Streams are regulated by four major flood-control dams, three navigation dams, and several smaller dams. All these dams obstruct fish movement. No fish that migrate to or from the ocean have ever been common in the basin, although some native fish, notably suckers, are strongly migratory within and near the basin. Ninety miles of the Kanawha River main stem are regulated for barge navigation by large locks and dams at London, Marmet, and Winfield. This entire reach of the river is dredged periodically.

Streams in the Blue Ridge Province follow a dendritic drainage pattern. Many mountain streams are cold and support (or formerly supported) brook trout populations, but the larger streams are warm. Stream water 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 slightly alkaline (7.0–8.0 pH units) 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. Many high-altitude streams are cold, and some streams draining areas larger than 100 mi^2 support trout populations. Bedrock in the northeastern part of the Appalachian Plateaus generally is inert, insoluble sandstone and shale. Stream water in this area typically is very dilute (30–100 mg/L dissolved solids) and poorly buffered, and some streams have been degraded by acid precipitation (Messinger, 1997). Streams in the rest of the Appalachian Plateaus typically have lower gradients than streams in the areas of highest altitude. The Greenbrier River and its eastern tributaries are underlain by limestone, and their waters are mildly alkaline (7.0–8.0 pH units), well buffered, and moderate in dissolved solids (150–200 mg/L). Bedrock in the western part of the Appalachian Plateaus Province is predominantly sandstone, shale, and coal, with interbedded limestone. The shale typically yields more solutes than the sandstone does, and relative amounts of shale increase in a gradient from south to north. Stream water in the western part of the Appalachian Plateaus contains more dissolved solids than any other part of the basin, with typical 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 stream water in this part of the basin is mildly alkaline and well buffered.



BASE FROM U.S. GEOLOGICAL SURVEY DIGITAL DATA, 1:2,000,000, 1992

Figure 1. Streams, towns, and other selected features of the Kanawha River Basin, West Virginia, Virginia, and North Carolina.

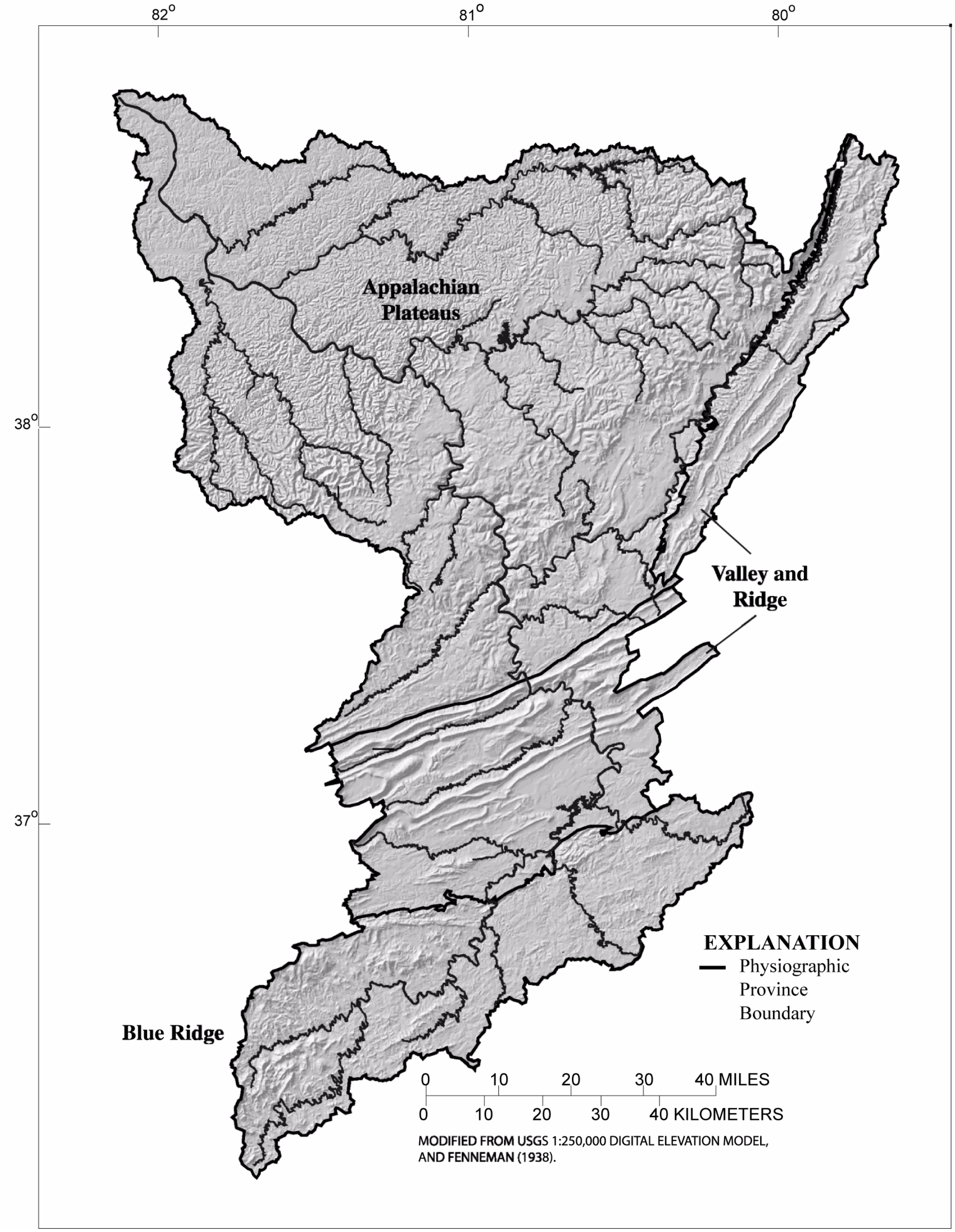


Figure 2. Altitude in the Kanawha River Basin is greatest in the northeastern Appalachian Plateaus and southern Blue Ridge, and least in the western Appalachian Plateaus.

The basin is mostly forest (81 percent) with a substantial amount of agricultural land (16 percent) (Multi-Resolution Land Characteristics Interagency Consortium, 1997). 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 produces about 7 percent of the coal mined in the United States, mostly from a band of Pennsylvanian-age rocks in West Virginia (fig. 3). Where coal is minable, it has usually been mined repeatedly, using different methods (Paybins and others, 2001). Numbers of active surface and underground mines and abandoned mines are all generally greatest in the areas with the most total coal production, complicating attempts to separate the effects of these factors. Major hydrologic effects of coal mining include addition of sulfate, aluminum, iron, and manganese to water, and increase in stream sedimentation. Base flow is increased downstream from valley fills (Wiley and others, 2001), but subsidence from underground mining beneath valley floors can dewater aquifers and streams (Hobba, 1981).

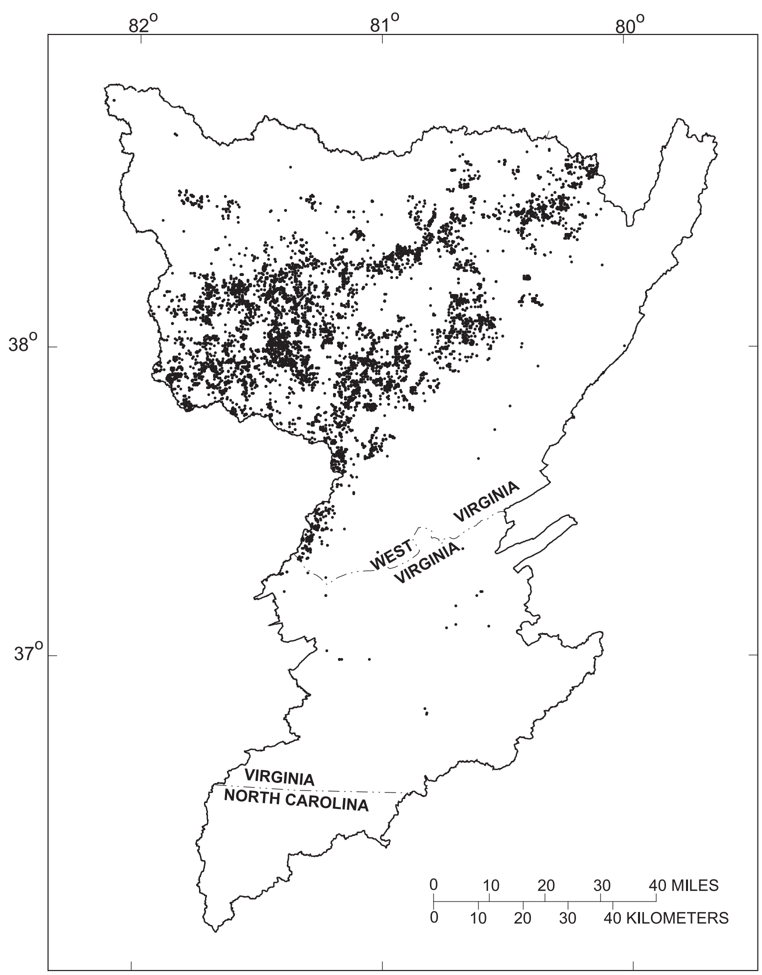


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Figure 3. Coal mines in the Kanawha River Basin are concentrated in a band ranging from southwest to northeast.

The New River may be among the oldest rivers in the world, although the claim that it is the second oldest river in the world is no longer considered to be well-founded (Swift, 2001; Lessing, 1997). Until about 2 million years ago, the New River was the headwater of the Teays River, the master stream flowing from the central Appalachian Mountains toward the Gulf of Mexico (Fridley, 1950). The native fish fauna of the New River is probably affected by both the New River's ancient position as head of the Teays River, and by combinations of geomorphic barriers and climate changes during times of glaciation (Jenkins and Burkhead, 1994).

Fish Distribution

Kanawha Falls is the primary physical barrier that divides the distinct fish fauna of the New River System from that of the Upper Ohio River System (fig. 4). About 90 native species are known from basin streams downstream from Kanawha Falls. This area, referred to as the Kanawha River System, is, along with other river basins throughout West Virginia, Ohio, Pennsylvania, New York, and Maryland, part of the Upper Ohio River System (Hocutt and others, 1986). Upstream from Kanawha Falls, the New River System includes the New and Gauley Rivers, their tributaries, and about one mile of the Kanawha River. The New River System has no more than 45 native species, 8 of which are endemic (found nowhere else in the world) (Jenkins and Burkhead, 1994). Many or most of the native species of the New River System are cold tolerant and thought to be relicts of Pleistocene glaciation (Jenkins and Burkhead, 1994). Many researchers have studied the routes of dispersal for the rest of the native species (Cope, 1868; Addair, 1944; Hocutt and others, 1978, Hocutt and others, 1979; Jenkins and Burkhead, 1994). Whatever the route of natural dispersal into the New River System, at the arrival of Europeans the New River was a depauperate (lacking in species) warm-water system surrounded by environmentally similar stream systems with richer faunas.

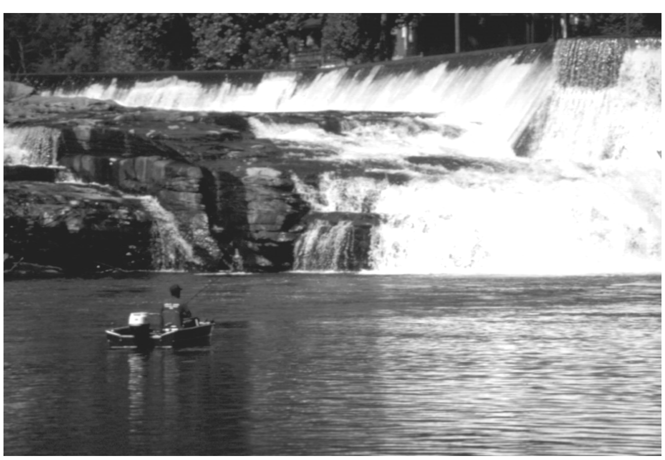

Figure 4. Kanawha Falls has been a barrier to fish movement for about 2 million years. Photograph by Steve Shaluta, West Virginia Division of Tourism, and used with permission.

Starnes and Etnier (1986) consider much of all fish zoogeography speculative. The native status of several fish species in the New River System is not definitely known, because studies extensive enough to document fish species distribution were not done until after many non-native species were well established in many streams. Stocking records show that some fish species were introduced soon after the first survey of the fish in the basin, when collections were made at only four sites in Virginia (Cope, 1868; Jenkins and Burkhead, 1994). The second survey of the basin's fish (at fewer than 10 sites) was made in response to a reported precipitous decline in Appalachian Plateaus fish populations caused by elimination of the virgin forest and related events, including widespread fires and commercial harvesting of stream fish using explosives (Goldsborough and Clark, 1908; Clarkson, 1964). No extensive basinwide fish collections were made until the 1930's, well after fisheries managers had pursued aggressive stocking programs but probably before rapid transportation enabled anglers to move bait species extensively across drainage boundaries.

Addair (1944) collected fish throughout the West Virginia part of the basin during the 1930's. He collected 28 fish species from about 50 sites upstream from Kanawha Falls, and some of these (smallmouth, spotted, and rock bass, common carp) were known introductions. Addair collected fish only by seining. Fish collection technology has improved since the 1930's, making it possible to collect more species of fish from a given stream reach, including species that might have been present but not abundant during Addair's surveys. However, human movement of bait fish across drainage basin boundaries became widespread during or shortly after Addair's surveys. These trends combine to make the native status of species first collected in the basin since Addair's collections ambiguous. Scientific judgment of the native status of several species in the New River System has changed through time (Jenkins and others, 1972; Hocutt, Stauffer, and Jenkins, 1986; Jenkins and Burkhead, 1994). Known non-native fish species continue to expand their ranges in the New River System (Cincotta and others, 1999); this expansion suggests that some species presently considered native or tentatively native, which were first collected in the 1970's at only a few sites but are now more widespread, may not be native.

Taxonomic Status of Selected Fish

Many analyses of fish communities rely on counts of species, either the overall species in a collection or the number of species meeting some specific criterion. However, taxonomic status of some fishes is not clear-cut. Some fishes do not belong to clearly definable species, because they are in the process of evolving into separate species. Taxonomic status of some common, abundant fish species in the basin has been controversial. In particular, complexes in the genera *Nocomis* and *Luxilus* are problematic and have been of interest to taxonomists.

The genus *Nocomis*, the chubs, includes the river chub complex: the bull chub of the Atlantic Slope, the river chub of the Ohio River System, and the bigmouth chub of the New River (fig. 5). Lachner and Jenkins (1971) described the bigmouth chub as distinct from the river chub for evolutionary reasons, feeling that it represented the ancestral stock of the complex, which evolved in the pre-glacial Teays River. Jenkins and Burkhead (1994) refer to Lachner and Jenkins' (1971) designation of the bigmouth chub as a separate species from the river chub as "arbitrary" (p. 319), and in their key of fish species of Virginia, the only characteristic distinguishing the bigmouth chub from the river chub is location. Additionally, Jenkins and Burkhead (1994) cite an unpublished genetic study that found only minor differences between bigmouth and river chubs, and concluded the two taxa were the same species.

The genus *Luxilus*, one genus of shiners, has been at times grouped with another genus of shiners, *Notropis*. *Luxilus* includes the common shiner complex: the common shiner, white shiner, and striped shiner (fig. 6); although closely related, all three are considered separate species (Robins and others, 1991). Immature individuals of all three species are difficult to distinguish using only morphological characteristics, and are most difficult to distinguish in streams where

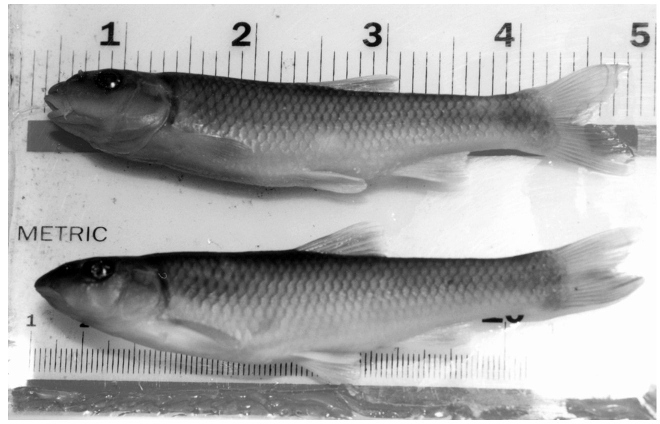

Figure 5. Bigmouth (top) and river chubs are separate species, although they are closely related and physically and functionally similar.

Figure 6. White (top) and striped shiners are separate species, although they are physically and functionally similar, and interbreed when in the same streams.

more than one are present (D.A. Cincotta, West Virginia Division of Natural Resources, oral commun., January 2000). The taxonomic status of the common and striped shiner has been controversial, although these two species are not as closely related as the bigmouth and river chub. The striped shiner formerly was considered a subspecies of the common shiner, but was designated as a species in the early 1960's (Etnier and Starnes, 1993). The two fish interbreed in the part of their ranges that overlaps. Although the offspring resulting from their crosses are not sterile, there appears to be selection pressure against them. Analysis of genetic markers of 42 sympatric populations found some gene flow between the two taxa, but that in 41 of the populations, partial or full reproductive isolation was maintained (Dowling and Moore, 1984). Etnier and Starnes (1993) consider arguments presented on both sides of the issue to be valid, and concluded that after most evidence was presented, “the question became philosophical.” Menzel (1976, 1977) and Buth (1979) consider the white shiner to have arisen from hybridization of the ancestral stocks of the evolutionarily diverging common and striped shiners. Jenkins and Burkhead (1994) comment that in the New River System, white shiners and striped shiners have similar color patterns (normally the character used to distinguish the two taxa), and consider this to indicate “a formerly unnoticed taxonomic problem.”

Acknowledgments

Joan Steven and Kim Smith, both of Charleston, West Virginia, volunteered their time to help survey fish. Dan Cincotta and Jeff Hyjenga of the West Virginia Division of Natural Resources and Jesse Purvis of the National Park Service also helped collect fish. Many employees of the U.S. Geological Survey from the Charleston, West Virginia, and Marion, Virginia offices assisted in the field. Harold Henderlite, Dennis Adams, Mike Eckenwiler, Janet Steven, Wes Gladwell, Melody Bova, Matt Wooten, Jeremy White, Charlynn Sheets, Ed Vincent, Mark Kozar, and Jim Eychaner all participated in several fish surveys, and Matt Wooten and Jeremy White helped process preserved fish.

MATERIALS AND METHODS

This study used methods of the USGS NAWQA Program. Fish were collected at sites that were part of two networks (fig. 7). In a “fixed-site network,” continuous flow, monthly and high-flow water chemistry, and one-time habitat structure, algal, invertebrate, and fish community, streambed sediment and fish tissue contaminant data were collected. In a “synoptic network,” water chemistry data were collected one time at 59 sites; habitat structure, invertebrate community, and streambed-sediment trace-element data were collected at 29 sites; and fish community data were collected at 10 sites.

The 11 fixed sites were divided into 2 groups. Four “integrator” sites along the main stem of the New and Kanawha River integrated the effects of the various environmental settings throughout the basin. Seven “indicator” sites were intended to represent important, relatively homogeneous environmental settings of physiography, land use, and geology. Coal mining and rural residential practices in the Appalachian Plateaus were identified as the land uses of greatest local concern for their adverse effects on water quality (West Virginia Division of Environmental Protection, 1998). One Kanawha River System coal-mining site, one New River System coal-mining site, and one New River System rural residential site were selected. A New River System site draining primarily high-altitude National Forest was selected, nominally as a reference site. To support national NAWQA Program interests, the effects of agriculture were assessed at one site in each of the three physiographic provinces in the basin. All three of these sites were in the New River System. The fixed sites were selected largely based on field reconnaissance done in the summer of 1996, from sites in the basin where the USGS had previously collected streamflow or water-quality data. Fish were collected at all fixed sites in late summer of 1997. At three of the indicator sites, fish were collected from three reaches each in late summer of 1998.

In late summer 1998, fish were collected at the 10 synoptic sites, all in West Virginia. The synoptic study was designed to characterize the water-quality effects of coal mining in the Appalachian Plateaus, and changes in water quality in this region since the end of the USGS–Bureau of Land Management Coal Hydrology Program in 1981. However, the 10 sites were selected to extend the sampling range of geographic conditions, and to characterize the relations between environmental disturbance and fish communities. These sites were divided equally between the New and Kanawha River Systems.

Data types collected at fixed and synoptic sites are listed in table 1. Environmental measurements and collections made at all fish sites are listed in table 2. All sites are listed in table 3.

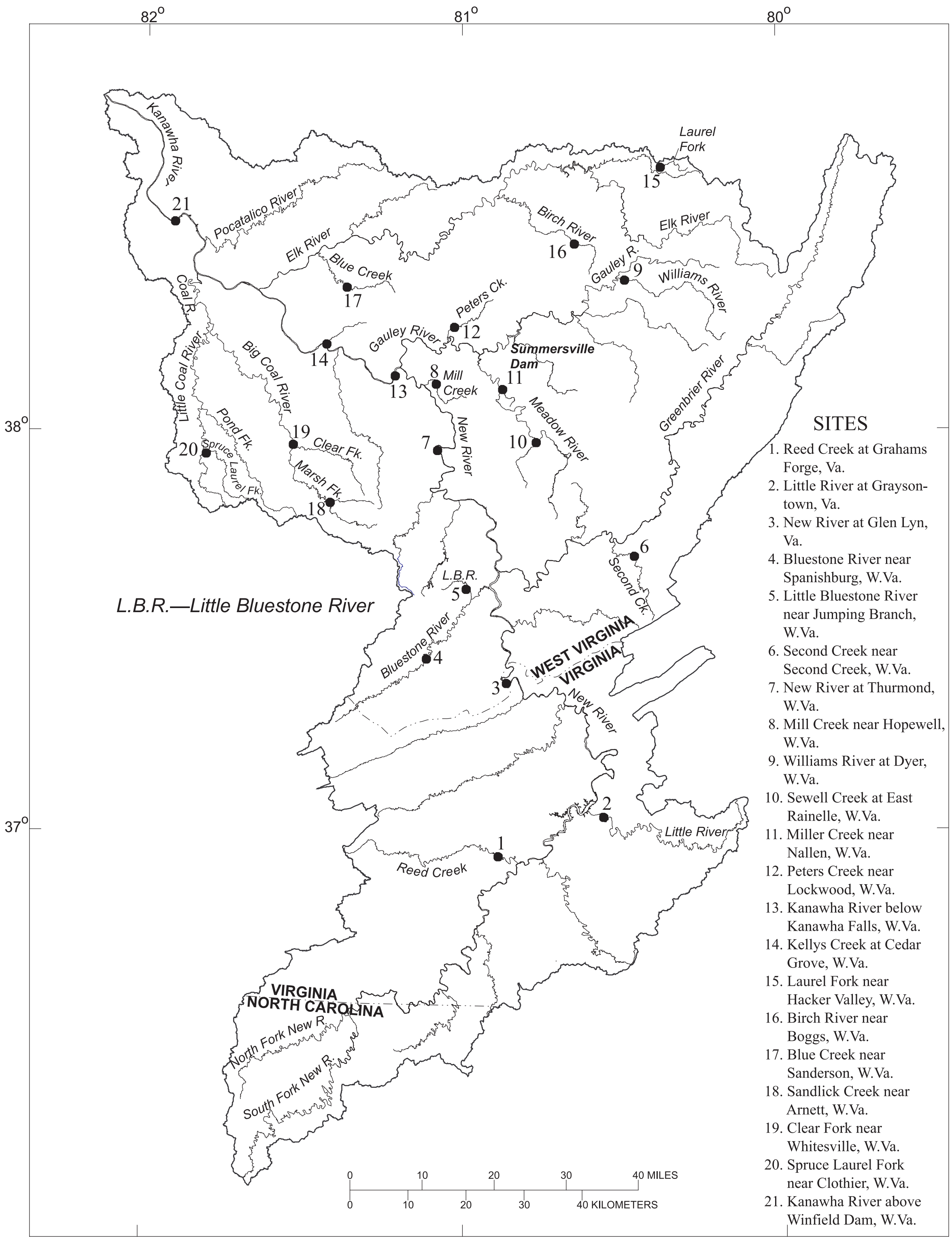

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Figure 7. Fish-collection sites in the Kanawha River Basin targeted important combinations of land use and physiography, particularly coal mining in the Appalachian Plateaus.

Table 1. Data collected at fixed and synoptic sites in the Kanawha River Basin, West Virginia, Virginia, and North Carolina

[PCB's, polychlorinated biphenyls; PAH's, polycyclic aromatic hydrocarbons; RTH, richest targeted habitat (after Porter and others, 1993, and Cuffney and others, 1993); QMH, qualitative multi-habitat (after Porter and others, 1993, and Cuffney and others, 1993); habitat structure measurements are described by Meador and others, 1993]

Data type	Fixed site	Synoptic site
Water		
Instantaneous discharge	x	x
Water temperature	x	x
Specific conductance	x	x
Dissolved oxygen	x	x
pH	x	x
Alkalinity	x	x
Major ions	x	x
Nutrients	x	
Iron, manganese, aluminum	x	x
Continuous temperature	x	
Continuous discharge	x	
Sediment contaminants		
Pesticides and PCB's	x	
PAH's	x	x
Trace elements	x	x
Fish tissue contaminants		
Pesticides and PCB's	x	
Trace elements	x	
Habitat structure		
Simple geomorphology	x	x
Detailed mapping	x	
Biota		
Algae, RTH	x	
Algae, QMH	x	
Invertebrates, RTH	x	x
Invertebrates, QMH	x	
Fish assemblage	x	x

Fish Collections

Fish were collected from reaches defined by a repeat of two consecutive geomorphic units, usually a repeat of a pool-riffle sequence (Meador and others, 1993a). Electrofishing was supplemented at most sites with kick seining in riffles (table 4). Fish were shocked from a motorboat at non-wadeable sites, with a towed barge at larger wadeable sites (including riffles at three sites where the pools were unwadeable), and with a backpack at the smallest sites. At all sites where ambient conductance was greater than about 50 µS, pulsed DC was used, and 120V AC was used at the other sites. Block nets were not used. Each reach was electrofished in two passes, with the kick seining typically done between passes.

All fish were identified to species. Up to 30 individuals of each species per pass were measured, weighed, and examined for external anomalies; after 30 individuals from one pass had been measured, the rest were weighted as a batch. As many fish as possible were identified on site and returned to the stream. Individuals of taxonomically problematic species, mostly some minnows and sculpins, were identified in the laboratory. Voucher specimens of all species (except those for which all the fish collected were too large, common carp and a few suckers) collected at each site were preserved and retained, and voucher identifications were confirmed by D.A. Cincotta of the West Virginia Division of Natural Resources Natural Heritage Program. Fish taxonomic data from 1997 and 1998 met NAWQA quality-assurance guidelines (Walsh and Meador, 1998). Fish were collected during the year's low-flow period, August–October.

Other Measurements

Invertebrate samples were collected at all 11 fixed sites from May 5 to July 3, 1997; samples were collected from the multiple reach sites from May 19 to June 11, 1998, including the reach sampled the previous year. Discharge and temperature were measured continuously at all fixed sites. Stream water was sampled monthly and additionally during high flow conditions at all sites (Shelton, 1994). At synoptic sites, water- and streambed sediment-chemistry, habitat structure, and invertebrate-community samples were collected in July 1998. Streamflow, stream-water and streambed-sediment chemistry, and invertebrate community data were published by Ward and others (1998 and 1999); continuous water-temperature data were published by Ward and others (2000).

The USGS's National Water-Quality Laboratory (NWQL) analyzed all streamwater samples for major ion concentrations and total and dissolved metal concentrations. Composite samples of the top 2–3 cm of stream-bottom material (Shelton and Capel, 1993) from each site were analyzed by the NWQL for metal and trace elements concentrations.

Table 2. Stream characteristics determined at all sites where fish were collected in the Kanawha River Basin during this study

Water	Streambed-sediment chemistry		Habitat structure
Instantaneous discharge	Aluminum	Strontium	Bank height
Specific conductance	Antimony	Sulfur	Stream width
pH	Arsenic	Tantalum	Channel width
Water temperature	Barium	Thorium	Bottom particle size
Air temperature	Beryllium	Tin	Mean depth
Dissolved oxygen	Bismuth	Titanium	
Total hardness	Cadmium	Uranium	
Dissolved hardness	Calcium	Vanadium	
Acidity	Inorganic carbon	Ytterbium	
Alkalinity	Organic carbon	Yttrium	
Dissolved calcium	Total carbon	Zinc	
Dissolved magnesium	Cerium	Acenaphthene	
Dissolved sodium	Chromium	Acenaphthylene	
Dissolved potassium	Cobalt	Anthracene	
Dissolved bicarbonate	Copper	9, 10-Anthraquinone	
Dissolved carbonate	Europium	Benz(a)anthracene	
Dissolved alkalinity	Gallium	Benzo(a)pyrene	
Dissolved sulfate	Gold	Benzo(b)fluoranthene	
Dissolved chloride	Holmium	Benzo(g,h,I)perylene	
Dissolved fluoride	Iron	Benzo(k)fluoranthene	
Dissolved silica	Lanthanum	Chrysene	
Dissolved solids	Lead	Dibenz(a,h)anthracene	
Total aluminum	Lithium	1,2-Dimethylnaphthalene	
Dissolved aluminum	Magnesium	1,6-Dimethylnaphthalene	
Total iron	Manganese	2,6-Dimethylnaphthalene	
Dissolved iron	Mercury	2-Ethylnaphthalene	
Total manganese	Molybdenum	Fluoranthene	
Dissolved manganese	Neodymium	9H-Fluorene	
	Nickel	Indeno1,2,3-c,d,pyrene	
	Niobium	1Methyl-9H-fluorene	
	Phosphorus	2-Methyl-9H-anthracene	
	Potassium	1-Methylphenanthrene	
	Scandium	1-Methylpyrene	
	Selenium	Naphthalene	
	Silver	Phenanthrene	
	Sodium	Pyrene	
		2,3,6-Trimethylnaphthalene	

Table 3. Station numbers, locations, and selected habitat-structure characteristics of all reaches of fish-community collection sites in the Kanawha River Basin

[D50, median bottom-material size; No., number; ft, feet; m, meters; mi^2, square miles; mm,millimeters; <, actual value is less than value shown; ND, not done]

Site	Station No.	Reach	Site type	Latitude	Longitude	Habitat structure characteristics					
						Drainage area (mi^2)	Altitude (ft)	Channel width (m)	Stream width (m)	Bank height (m)	D50 (mm)
Reed Creek at Grahams Forge, Va.	03167000	A	fixed	36° 56′ 22″	80° 53′ 13″	247	1,925	36.2	32	1.2	194
Reed Creek at Grahams Forge, Va.	03167000	B	fixed	36° 56′ 22″	80° 53′ 13″	247	1,925	40.3	32.8	2.6	194
Reed Creek at Grahams Forge, Va.	03167000	C	fixed	36° 56′ 22″	80° 53′ 13″	247	1,925	45.6	34.8	2.4	194
Little River at Graysontown, Va.	03170000	A	fixed	37° 02′ 15″	80° 33′ 25″	300	1,816	68.6	46.4	2.2	53
New River at Glen Lyn, Va.	03176500	A	fixed	37° 22′ 22″	80° 51′ 39″	3,768	1,490	120	75	15	ND
Bluestone River near Spanishburg, W.Va.	03178000	A	fixed	37° 26′ 00″	81° 06′ 40″	199	2,051	27.5	18.5	3.4	<2
Little Bluestone River near Jumping Branch, W.Va.	3756280805911339	A	synoptic	37° 56′ 28″	80° 59′ 11″	26.4	1,600	18.8	9.6	2.2	102
Second Creek near Second Creek, W.Va.	03183000	A	fixed	37° 41′ 05″	80° 27′ 25″	80.8	1,811	24.8	12.9	1.6	75
New River at Thurmond, W.Va.	03185400	A	fixed	37° 57′ 18″	81° 04′ 36″	6,687	1,031	200	100	20	ND
Mill Creek near Hopewell, W.Va.	380715081045001	A	synoptic	38° 07′ 15″	81° 04′ 50″	22.4	1,300	16.9	7.3	2	56
Williams River at Dyer, W.Va.	03186500	A	fixed	38° 22′ 44″	80° 29′ 03″	128	2,193	58.1	29.6	3.6	157
Williams River at Dyer, W.Va.	03186500	B	fixed	38° 22′ 44″	80° 29′ 03″	128	2,193	47	36.7	3	157
Williams River at Dyer, W.Va.	03186500	C	fixed	38° 22′ 44″	80° 29′ 03″	128	2,193	53.7	46.2	2.5	157
Sewell Creek at East Rainelle, W.Va.	375826080455339	A	synoptic	37° 58′ 26″	80° 45′ 53″	40.1	2,400	17.7	9.3	3.1	<2
Miller Creek at Nallen, W.Va.	380624080521601	A	synoptic	38° 06′ 24″	80° 52′ 16″	8.79	1,900	21.2	4.1	0.5	79
Peters Creek near Lockwood, W.Va.	03191500	A	fixed	38° 15′ 45″	81° 01′ 24″	40.2	1,060	23.4	13.5	3	<2
Kanawha River below Kanawha Falls, W.Va.	03193000	A	fixed	38° 08′ 17″	81° 12′ 52″	8,371	621	325	130	20	ND
Kellys Creek at Cedar Grove, W.Va.	381313081253739	A	synoptic	38° 13′ 13″	81° 25′ 37″	24.1	600	13.8	10.3	1.3	31
Laurel Fork near Hacker Valley, W.Va.	383912080225339	A	synoptic	38° 39′ 12″	80° 22′ 53″	11.5	1,515	12.4	6.3	1.8	79
Birch River at Boggs, W.Va.	382811080383339	A	synoptic	38° 28′ 11″	80° 38′ 33″	16.3	1,454	20.4	12.6	1.6	93
Blue Creek at Sanderson, W.Va.	382145081215239	A	synoptic	38° 21′ 45″	81° 21′ 52″	50.1	710	69.3	39.3	1.5	40
Sandlick Creek near Arnett, W.Va.	374928081245239	A	synoptic	37° 49′ 28″	81° 24′ 52″	19.9	1,640	14	8	1.3	<2
Clear Fork at Whitesville, W.Va.	03198350	A	fixed	37° 58′ 08″	81° 31′ 55″	62.8	819	17.9	9.8	2.1	51
Clear Fork at Whitesville, W.Va.	03198350	B	fixed	37° 58′ 08″	81° 31′ 55″	62.8	819	23.7	10.1	2.4	51
Clear Fork at Whitesville, W.Va.	03198350	C	fixed	37° 58′ 08″	81° 31′ 55″	62.8	819	22.4	10.4	2.2	51
Spruce Laurel Fork near Clothier, W.Va.	375645081482339	A	synoptic	37° 56′ 45″	81° 48′ 23″	31.8	810	23.6	17	1.5	68
Kanawha River above Winfield Dam, W.Va.	03201300	A	fixed	38° 31′ 32″	81° 54′ 40″	11,809	566	325	240	25	ND

Table 4. Fish collection dates and methods, Kanawha River Basin

[**Collection No.:** Refers only to multi-year, multi-reach sites. **Current type:** AC, alternating current; DC, direct current. No., number]

Site	Collection No.	Collection date(s)	Reach	Electrofishing method(s)	Current type	Number of passes
Reed Creek at Grahams Forge, Va.	1	10-02-97	A	Towed barge	pulsed DC	2
	4	9-01-98	C	Towed barge	pulsed DC	2
	3	9-02-98	B	Towed barge	pulsed DC	2
	2	9-03-98	A	Towed barge	pulsed DC	2
Little River at Graysontown, Va.		9-18-97	A	Towed barge	pulsed DC	2
New River at Glen Lyn, Va.		10-06-97	A	Boat	pulsed DC	2
		10-06-97	A	Towed barge	pulsed DC	2
Bluestone River near Spanishburg, W.Va.		8-07-97	A	Towed barge	pulsed DC	2
Little Bluestone River near Jumping Branch, W.Va.		9-24-98	A	Backpack	pulsed DC	2
Second Creek near Second Creek, W.Va.		8-28-97	A	Towed barge	pulsed DC	2
New River at Thurmond, W.Va.		9-23-97	A	Boat	pulsed DC	2
		9-23-97	A	Towed barge	pulsed DC	2
Mill Creek near Hopewell, W.Va.		9-21-98	A	Backpack	pulsed DC	2
Williams River at Dyer, W.Va.	1	8-27-97	A	Towed barge	AC	2
	4	8-19-98	C	Towed barge	AC	2
	3	8-20-98	B	Towed barge	AC	2
	2	8-20-98	A	Towed barge	AC	2
Sewell Creek at East Rainelle, W.Va.		9-15-98	A	Backpack	pulsed DC	2
Miller Creek at Nallen, W.Va.		9-15-98	A	Backpack	pulsed DC	2
Peters Creek near Lockwood, W.Va.		8-26-97	A	Towed barge	pulsed DC	2
Kanawha River below Kanawha Falls, W.Va.		9-24-97	A	Boat	pulsed DC	2
		9-24-97	A	Towed barge	pulsed DC	2
Kellys Creek at Cedar Grove, W.Va.		9-14-98	A	Backpack	pulsed DC	2
Laurel Fork near Hacker Valley, W.Va.		9-16-98	A	Backpack	pulsed DC	2
Birch River at Boggs, W.Va.		9-17-98	A	Backpack	pulsed DC	2
Blue Creek at Sanderson, W.Va.		9-23-98	A	Backpack	pulsed DC	2
Sandlick Creek near Arnett, W.Va.		9-23-98	A	Backpack	pulsed DC	2
Clear Fork at Whitesville, W.Va.	1	9-04-97	A	Towed barge	pulsed DC	2
	4	8-26-98	C	Towed barge	pulsed DC	2
	3	8-27-98	B	Towed barge	pulsed DC	2
	2	8-28-98	A	Towed barge	pulsed DC	2
Spruce Laurel Fork at Clothier, W.Va.		9-22-98	A	Towed barge	pulsed DC	1
		9-22-98	A	Backpack	pulsed DC	1
Kanawha River above Winfield Dam, W.Va.		10-09-97	A	Boat	pulsed DC	2

Wetted channel width, bankfull height, and bankfull width were measured at three transects corresponding to the two riffles and the intervening pool in a reach (Meador and others, 1993b). Depth and velocity were measured at three points along each transect, and the dominant and subdominant substrate class were identified at these three points. Streambed particle-size distribution was characterized by measuring the intermediate axis of 100 streambed particles equally distributed among the three transects.

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 obtain taxa density.

The Multi-Resolution Land Characteristics (MRLC) data set, which incorporates Landsat data from 1986 to 1994, was compared to field data. Coal-production data were derived from production figures reported by companies to the Energy Information Administration. For the period 1980-95, the most recent year for which data were available, production data was assembled and matched with location coordinates for mining permits (Emil Attanasi, U.S. Geological Survey, written commun., 1997). If the associated location fell within a basin's drainage area, the production value was assigned to that basin. The assignment of coal production to a single point introduces error because both surface and underground mines cover wide areas, not just the coordinates indicated on the permit. Surface and underground mines can cover thousands of hectares and span drainage divides, and underground mines may transfer water between basins.

Statistical analysis of water-chemistry samples from the fixed sites included only the summer, low-flow sample from the year the fish community was sampled that was most comparable in season and flow to the synoptic sampling period in July 1998. Cluster analysis of water-chemistry data grouped sites similarly whether a single sample or median for the entire 2-year period was considered, and a single sample was considered to be most comparable to the synoptic data.

CURRENT FISH DISTRIBUTION

In 1997–98, 26,843 fish of 81 species were collected as part of this study. The 81 species were divided among nine families. Cyprinidae, the minnow family, was the dominant fish family in the basin in terms of species (31), individuals (17,385), and mass (316,000 g). The three most abundant fish species in the basin were the central stoneroller (4,927), rosyface shiner (1,767), and rock bass (1,620). The three dominant fish species in the basin by mass were the common carp (158,000 g), rock bass (109,000 g), and central stoneroller (85,500 g). The northern hog sucker was the most widespread fish, present at 18 sites. The central stoneroller and creek chub were both present at 16 sites. All fish-community data from this study were published (Ward and others, 1999).

Non-native fish continue to expand their range in the New and Gauley Rivers and their tributaries; in this study, species were collected for the first time at several previously sampled sites. Within the New River System, distribution of many species, including native species, is spotty (Jenkins and Burkhead, 1994). Distribution of native species was probably influenced by the basin's abundant waterfalls, cascades, and other natural barriers to fish movement, but during the twentieth century, native and non-native species have been increasingly moved into and through the basin by humans. Margined madtoms, a popular bait species, were collected from Second Creek near Second Creek, at a reach that had been sampled in 1979. Margined madtoms are native to some parts of the New River and some of its tributaries, but had never before been collected from the Greenbrier River subbasin. Telescope shiners, natives of the Tennessee River Basin, have been collected in the New River since 1958, and continue to expand their range. Telescope shiners were collected for the first time from Williams River at Dyer in 1997, from a reach that was sampled in the 1970s and again in the early 1990s (Hocutt and others; Cincotta and others, 1999); this was their first collection upstream from Summersville Dam. Telescope shiners also were first collected from two Meadow River tributaries in 1998. Least brook lamprey were collected from Williams River at Dyer in 1997, their second collection from the Gauley River subbasin. Addair (1944) remarked on the absence of least brook lamprey upstream from Kanawha Falls; one lamprey was collected at one site in the Gauley River subbasin by Hocutt and others (1978). Populations of all these species were well established, and the ongoing expansion of their ranges suggests that all were relatively recent bait-bucket introductions to the depauperate New River System. Human movement of fish throughout the New River System is likely to continue to make the New River fish fauna highly unstable.

Some new distribution records in the Kanawha River System are unlikely to result from human movement of fish. Several species were collected from tributaries in the Coal River subbasin outside their previously recorded range. However, in contrast with the New River System, the Coal River distribution records were for large tributaries where few surveys had been done since the 1930s. Mottled sculpin, bluebreast darter, river carpsucker, blacknose dace, and longnose dace all were collected for the first time from Clear Fork at Whitesville or Spruce Laurel Fork at Clothier, major tributaries to the Big and Little Coal Rivers, respectively. Several of these records were the most upstream in their respective forks of the Coal River, although all these species had been collected from the Coal River subbasin. It is unlikely that these records represent range expansions, but rather undersampling of streams that have often been overlooked by investigators.

Non-native fish species are regarded widely by biologists as disturbances to ecosystems (Miller and others, 1988; Tyus and Sanders, 2000). Adverse effects to ecosystems, communities, or populations are known to be caused by invasive species, such as common carp. The unknown native status of many fish in the Kanawha River Basin, combined with the original patchy distribution of fishes, makes measuring environmental disturbance using abundance of non-native fish problematic. Native or non-native status of a fish species at a given site depends on the spatial scale at which such status is considered. When two sites are compared, their relative standing in percentage of non-native species can change depending on the spatial scale at which native status is considered (table 5). All the species for which range expansions were recorded in this study are native to eastern North America, and all but telescope shiners are native to the Ohio River Basin, including the Kanawha River Basin. If the unit for which species range was being considered was either the entire Kanawha River Basin or the New River and Kanawha River Systems, no range expansions were recorded.

In some parts of the United States, the proportion of non-native species consistently increases as streams degrade (Maret and others, 1999; Waite and Carpenter, 2000). In the Pacific Northwest, undegraded streams typically are cold and depauperate. In this region, stream degradation may take the form of increases in temperature and nutrients caused by logging, agriculture, and urbanization, and the non-native fish are species that are widely found in warmwater habitat. In the Kanawha River Basin, typical stream degradation usually includes sedimentation and increases in total dissolved solids. The range expansion of fish species in the New River System since the 1970s has come during a time when broad regulations have been implemented and widely regarded as having improved water quality, nationally and in the basin. Concentrations of total iron and manganese in water have decreased, and pH increased, since Congress enacted the Surface Mine Control and Reclamation Act (SMCRA) in 1977 (Paybins and others, 2001). Although regional sedimentation data from before and after SMCRA are unavailable, most observers believe that regulatory requirements designed to decrease stream sedimentation from surface mining have been at least partially effective. During the same period, some land uses, notably agriculture, have decreased in the basin, while industrial discharges to streams in the basin have decreased. Physical and regulatory environments in the Kanawha River System have undergone changes similar to those in the New River System, but non-native species have not expanded their ranges in the Kanawha River System. It is unlikely that increases in richness and abundance of non-native fish in the New River System reflect degradation in water chemistry or physical habitat quality caused by changes in land use.

Table 5. Proportion of individual fish as non-native species in collections from Bluestone River near Spanishburg, W.Va., and Second Creek near Second Creek, W.Va., with native status assessed at different spatial scales

[**Ohio River and New River:** Native status from Jenkins and Burkhead (1994). **Bluestone River and Second Creek:** Native status from Stauffer and others (1995). blank, native; nn, non-native]

Bluestone River near Spanishburg

Vshflhv	Number of individuals	Percentage of individuals native to:		
		Ohio River	New River	Bluestone River
Central stoneroller	5			
Bigmouth chub	7			
Bluntnose minnow	4			
Creek chub	1			
Telescope shiner	4	nn	nn	nn
Whitetail shiner	15	nn	nn	nn
White sucker	1			
Northern hog sucker	1			
Muskellunge	1		nn	nn
Rock bass	275		nn	nn
Smallmouth bass	11		nn	nn
Spotted bass	3			
Largemouth bass	9		nn	nn
Redbreast sunfish	144		nn	nn
Green sunfish	3			
Greenside darter	2			
Percentage of non-natives		4	94	94

Vhfrqg#Fuhhn#qhdu Vhfrqg#Fuhhn

Species	Number of individuals	Percentage of individuals native to:		
		Ohio River	New River	Second Creek
Central stoneroller	825			
Bigmouth chub	29			
Bluntnose minnow	21			
Longnose dace	5			
Creek chub	11			
Whitetail shiner	20	nn	nn	nn
White shiner	51			nn
Rosyface shiner	4			
White sucker	6			
Northern hog sucker	27			
Margined madtom	69			nn
Mottled sculpin	146			
Banded sculpin	10			
Rock bass	70		nn	nn
Smallmouth bass	7		nn	nn
Green sunfish	2			
Telescope shiner	532	nn	nn	nn
Rainbow darter	3		nn	nn
Fantail darter	168			
Greenside darter	5			
Percentage of non-natives		27	31	37

COMPARISON OF FISH COMMUNITIES

Two different analytical approaches were used to compare and contrast fish communities within the basin. With the first approach, the affinities of fish communities were related among different sites using the Jaccard Similarity Coefficient. With the second approach, a multivariate clustering technique was used to distinguish differences among groups of similar sites, and discuss differences among groups and similarities within groups.

Similarities Among Fish Communities

The Jaccard Similarity Coefficient (S_j) is a measure of the similarity in species composition among groups (Wilkinson, 1998). S_j is determined by dividing the number of species in common between two samples by the total number of species in those two samples, without considering abundance. S_j is expressed as a decimal value between zero and one, and a greater value represents greater similarity between two groups.

Samples from one of the three multi-year, multi-reach sites were less similar than some samples from different streams. S_j ranged from 0.704 to 0.833 among the four samples from Clear Fork at Whitesville, 0.548 to 0.741 among the four samples from Reed Creek at Grahams Forge, Clear Fork at Whitesville, and 0.667 to 0.867 among the four samples from Williams River at Dyer. Site pairings that had $S_j > 0.5$ included Birch River at Boggs with Sandlick Creek near Arnett (0.500), Bluestone River near Spanishburg with Second Creek near Second Creek (0.500), Clear Fork at Whitesville with Blue Creek at Sanderson (0.560) and with Spruce Laurel Fork at Clothier (0.583), and New River at Glen Lyn with New River at Thurmond (0.529). Among the multi-year, multi-reach sites, the same reach sampled in the two different years was never the most or least similar among sample pairings from a site. S_j values of 1997 and 1998 samples from the primary reach were 0.826 at Clear Fork, 0.654 at Reed Creek, and 0.765 at Williams River. The relatively low Sj values from Reed Creek might have been caused by differences in habitat structure among the reaches, or might have reflected the difficulty of collecting a representative sample at a site of its size (drainage area = 247 mi^2; average stream width = 40.7 m).

Groupings of Fish Communities

Two-way indicator species analysis (TWINSPAN) is a statistical method and computer program that separates collections by reciprocal averaging of species composition and relative abundance data (Gauch, 1982). Unlike most types of cluster analysis, TWINSPAN splits samples by differences rather than grouping them by similarities, and designates indicator species and numbered “pseudospecies” (calculated by abundance, with increasing numbers indicating increased abundance) that separate the groups. TWINSPAN was used to analyze the fish-community data twice, using two different taxonomic scenarios (figs. 8 and 9). The taxonomic status recognized by Robins and others (1990) was used in the first analysis. In the second analysis, two closely related species complexes were treated as single species; the river chub was combined with the bigmouth chub (*Nocomis*) and the white shiner was combined with the striped shiner (*Luxilus*). The second analysis appeared to provide more ecological insight than the first. Under both taxonomic scenarios, TWINSPAN grouped all four samples collected from multi-year, multi-reach sites more closely than any other samples (figs. 8, 9). In both analyses, the first separation was between the two largest sites (Kanawha River below Kanawha Falls and Kanawha River above Winfield Dam) and the rest of the sites. The indicator species, gizzard shad, is a filter feeder collected only from the main stem of the Kanawha River.

Under the accepted taxonomic scenario, the second order TWINSPAN split generally grouped sites by physiography, but with unexpected groupings (fig. 8). The first group of sites was a mix of sites of different sizes from throughout the basin, and the second group was entirely from the Appalachian Plateaus. White shiners and redbreast sunfish were indicators for the first group, and fantail darters and striped shiners were indicators for the second group. The importance of white and striped shiners in separating these groups was problematic, because of the functional similarity of the two species. The third-level split of the first group was uninterpretable; a Kanawha River System site of about 24 mi^2, Kellys Creek at Cedar Grove, was grouped with New River at Thurmond, which drains 6,697 mi^2.

Under the taxonomic scenario which treated the *Nocomis* and *Luxilus* complexes as single species, the second-order split was dominated by stream size, and the third-order splits followed physiography (fig. 10). The first group of sites (with one exception) drained more than 30 mi^2 and the second group (also with one exception) drained less than 30 mi^2. The indicator species dividing the two groups was smallmouth bass, which preferred the larger sites. In the first group, the third-order split was between sites in the New River System draining more than 199 mi^2 and sites from the Appalachian Plateaus draining between 24 and 128 mi^2. The indicator pseudospecies was

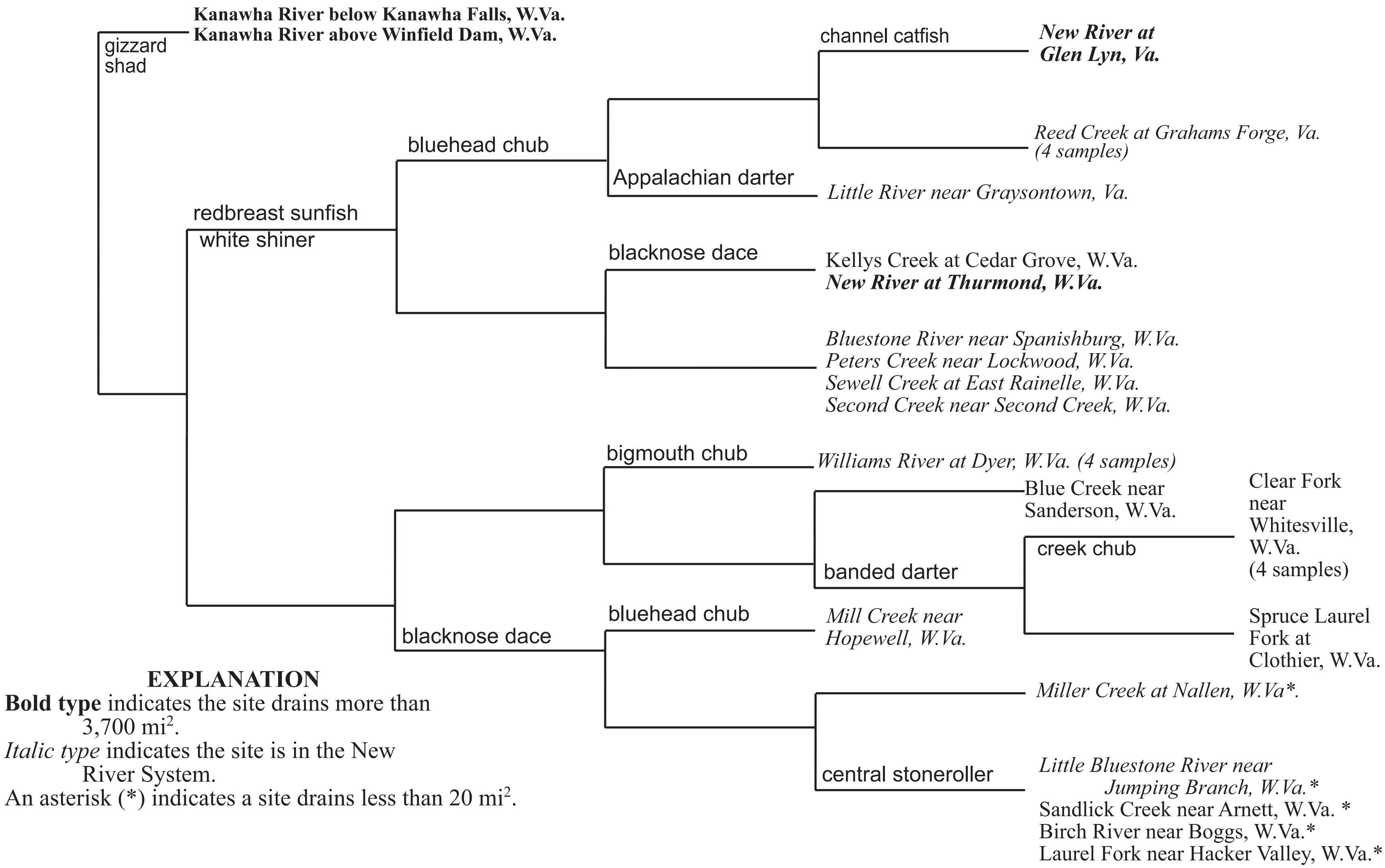
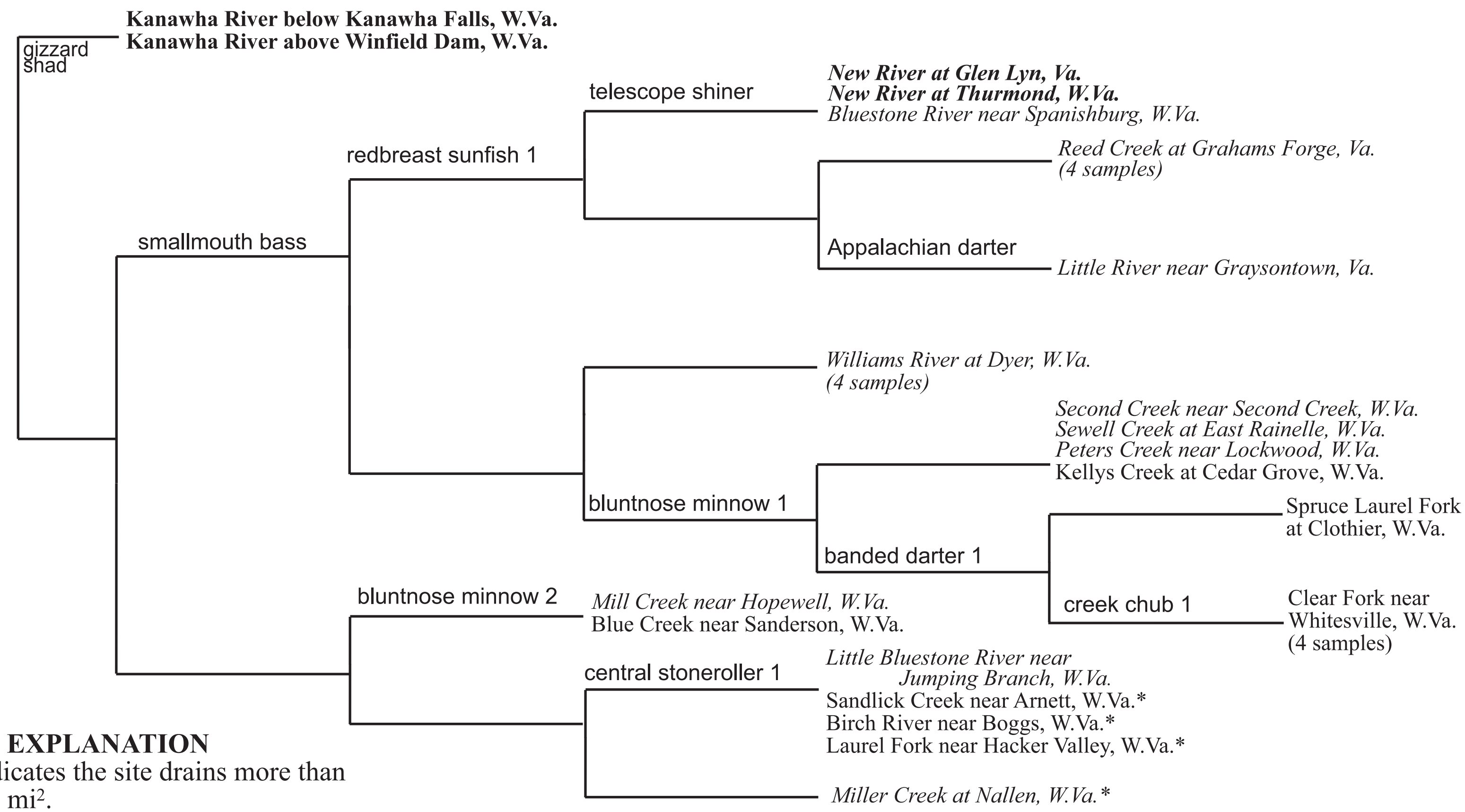


Figure 8. When using accepted taxonomy, TWINSPAN generally separates sites by size and physiography, but with some puzzling groupings. The *Luxilus* complex, white and striped shiners, is important in defining groups.



EXPLANATION

Bold type indicates the site drains more than 3,700 mi^2.

Italic type indicates the site is in the New River System.

An asterisk (*) indicates a site drains less than 20 mi^2.

Figure 9. When two closely related species complexes, the white/striped shiners and the bigmouth/river chubs, are each treated as single species, TWINSPAN separates fish communities in the Kanawha River Basin primarily by size.

redbreast sunfish 1, which preferred the larger sites. The fourth-order splits in both groups were interpretable. Telescope shiners split a group made up of New River at Thurmond, New River at Glen Lyn, and Bluestone River near Spanishburg, three sites in or near the Appalachian Plateaus but draining large areas in the Valley and Ridge, from Reed Creek at Grahams Forge (Valley and Ridge) and Little River at Graysontown (Blue Ridge), two agricultural sites. In the other subgroup of the large-stream group, bluntnose minnows (pseudospecies 2) split a group of six sites from the Appalachian Plateaus from Williams River at Dyer. Within the bluntnose minnow group, banded darters (pseudospecies 1) split the two sites from the Coal River subbasin from a group including three mining sites and Second Creek near Second Creek, an agricultural site in the Appalachian Plateaus. In the small-stream group, bluntnose minnows (pseudospecies 2) split Blue Creek at Sanderson and Mill Creek near Hopewell, two small- to medium-sized sites with well-developed riffles and wooded banks, from a group including the four smallest sites in the study along with Little Bluestone River near Jumping Branch, a site upstream from a waterfall, which was among the most depauperate sites in the study.

In general, TWINSPAN and Jaccard Similarity analysis gave similar results. Jaccard Similarity analysis showed close affinity between Blue Creek at Sanderson with Clear Fork at Whitesville and Spruce Laurel Fork at Clothier, although TWINSPAN split them into different third-order groups. The other major difference was that TWINSPAN split Second Creek near Second Creek and Bluestone River near Spanishburg into different third-order groups, although these sites had a high *Sj* (0.500).

RELATION OF FISH COMMUNITIES TO SELECTED ENVIRONMENTAL FACTORS

Two approaches were used to relate fish communities to selected environmental factors. In the first, fish-community metrics are related to environmental factors and, to the degree practical, used to compare sites. In the second, ordination is used to mathematically relate relative abundance of fish species to environmental factors.

Metrics are attributes used to measure the quality, health, or integrity of a biological assemblage. Of many proposed metrics, only a few have proven to be robust and widely useful for assessing effects of disturbances on streams (table 6; Karr and Chu, 1999; Barbour and others, 1999). To be useful, a metric must both quantify a consistent, predictable response to disturbance and be robust despite inconsistencies in sampling efficiency. Metrics assess different structural (taxonomic composition) or functional (trophic, reproductive, or behavioral) aspects of the fish community (table 6). Metrics may be based on numbers of taxa meeting a criterion for describing a fish community (taxa-richness metrics), or on the proportion of the community meeting such a criterion (proportional metrics). Metrics commonly are combined into a multimetric index, or a combination of several metrics (Karr, 1981). A useful metric-based assessment should use metrics representing different aspects of the community and provide a broad ecological base for comparing communities among sites (Karr and Chu, 1999; Smogor and Angermeier, 1999a, 1999b; Angermeier and others, 2000).

Determining criteria for scoring metrics is not straightforward. For example, a common and useful metric is proportion of a fish community as pollution-tolerant individuals. Although most ichthyologists agree on the tolerance to disturbance shown by most fish species, they disagree on the tolerance of several common species. Gizzard shad, central stonerollers, river chubs, northern hog suckers, mottled sculpins, and rock bass are abundant or widespread fish species in the Kanawha River Basin that different researchers have deemed to have different tolerance to pollution (Barbour and others, 1999). “Tolerance” values represent an integration of different physiological effects, which may or may not be individually well known. Condensing all these effects into a single value is necessarily a compromise, and overlooks much of the complexity found in nature. Most fish species respond differently to different types of disturbance. Green sunfish, for example, are highly tolerant of organic and nutrient pollution, sedimentation, and low dissolved-oxygen concentration. They were appropriately selected to indicate degraded conditions in the original Index of Biotic Integrity (IBI), which was developed to measure stream disturbance caused primarily by agriculture and urbanization (Karr, 1981). However,

Table 6. Metric scoring criteria for fish species collected in the Kanawha River Basin

[n, no; y, yes]

Name	Scientific name	Family	Native	Habitat	Feeding habit	Tolerance	Repro-ductive age (years)	Simple lithophil
Least brook lamprey	*Lampetra aepyptera*	Petromyzontidae	y	pelagic	filter	intolerant	6	n
Skipjack herring	*Alosa chrysochloris*	Clupeidae	y	pelagic	predator	intermediate	4	n
Gizzard shad	*Dorosoma cepedianum*	Clupeidae	y	pelagic	omnivore	tolerant	2	n
Central stoneroller	*Campostoma anomalum*	Cyprinidae	y	riffle	herbivore	tolerant	2	n
Rosyside dace	*Clinostomus funduloides*	Cyprinidae	y	pelagic	invertivore	intolerant	2	y
Whitetail shiner	*Cyprinella galactura*	Cyprinidae	y	pelagic	invertivore	intermediate	2	n
Spotfin shiner	*Cyprinella spiloptera*	Cyprinidae	y	pelagic	omnivore	tolerant	1	n
Common carp	*Cyprinus carpio*	Cyprinidae	n	pelagic	omnivore	tolerant	3	n
White shiner	*Luxilus albeolus*	Cyprinidae	y	pelagic	invertivore	tolerant	1	y
Crescent shiner	*Luxilus cerasinus*	Cyprinidae	y	pelagic	invertivore	intermediate	2	y
Striped shiner	*Luxilus chrysocephalus*	Cyprinidae	y	pelagic	invertivore	tolerant	2	y
Rosefin shiner	*Lythrurus ardens*	Cyprinidae	y	riffle	omnivore	intermediate	1	y
Bluehead chub	*Nocomis leptocephalus*	Cyprinidae	y	riffle	omnivore	intermediate	3	n
River chub	*Nocomis micropogon*	Cyprinidae	y	riffle	omnivore	intermediate	3	n
Bigmouth chub	*Nocomis platyrhynchus*	Cyprinidae	y	riffle	omnivore	intermediate	3	n
Golden shiner	*Notemigonus crysoleucas*	Cyprinidae	y	pelagic	invertivore	tolerant	2	n
Bigeye chub	*Notropis amblops*	Cyprinidae	y	pelagic	invertivore	intermediate	1	y
Emerald shiner	*Notropis atherinoides*	Cyprinidae	y	pelagic	invertivore	intermediate	1	n
Silverjaw minnow	*Notropis buccatus*	Cyprinidae	y	pelagic	omnivore	tolerant	1	y
Spottail shiner	*Notropis hudsonius*	Cyprinidae	y	pelagic	omnivore	intermediate	2	n
Silver shiner	*Notropis photogenis*	Cyprinidae	y	pelagic	invertivore	intermediate	1	y
Swallowtail shiner	*Notropis procne*	Cyprinidae	y	pelagic	omnivore	intermediate	2	y
Rosyface shiner	*Notropis rubellus*	Cyprinidae	y	pelagic	invertivore	intolerant	1	y
Saffron shiner	*Notropis rubricroceus*	Cyprinidae	y	pelagic	invertivore	intermediate	1	y
New River shiner	*Notropis scabriceps*	Cyprinidae	y	pelagic	invertivore	intermediate	2	y
Sand shiner	*Notropis stramineus*	Cyprinidae	y	pelagic	omnivore	intermediate	1	y
Telescope shiner	*Notropis telescopus*	Cyprinidae	n	pelagic	invertivore	intermediate	2	y
Mimic shiner	*Notropis volucellus*	Cyprinidae	y	pelagic	omnivore	intermediate	1	n
Kanawha minnow	*Phenacobius teretulus*	Cyprinidae	y	pelagic	invertivore	intermediate	2	y
Mountain redbelly dace	*Phoxinus oreas*	Cyprinidae	y	pelagic	herbivore	intermediate	1	y

Table 6. Metric scoring criteria for fish species collected in the Kanawha River Basin—*Continued*

Name	Scientific name	Family	Native	Habitat	Feeding habit	Tolerance	Repro-ductive age (years)	Simple lithophil
Bluntnose minnow	*Pimephales notatus*	Cyprinidae	y	pelagic	omnivore	tolerant	1	n
Fathead minnow	*Pimephales promelas*	Cyprinidae	n	pelagic	omnivore	tolerant	1	n
Blacknose dace	*Rhinichthys atratulus*	Cyprinidae	y	riffle	invertivore	tolerant	2	y
Longnose dace	*Rhinichthys cataractae*	Cyprinidae	y	riffle	invertivore	intermediate	2	y
Creek chub	*Semotilus atromaculatus*	Cyprinidae	y	pelagic	omnivore	tolerant	1	n
River carpsucker	*Carpiodes carpio*	Catostomidae	y	benthic, pool	omnivore	intermediate	3	y
Quillback	*Carpiodes cyprinus*	Catostomidae	y	pelagic	omnivore	tolerant	3	y
White sucker	*Catostomus commersoni*	Catostomidae	y	benthic, pool	invertivore	tolerant	3	y
Northern hog sucker	*Hypentelium nigricans*	Catostomidae	y	benthic, pool	invertivore	intermediate	3	y
Smallmouth buffalo	*Ictiobus bubalus*	Catostomidae	y	benthic, pool	omnivore	intermediate	3	y
Silver redhorse	*Moxostoma anisurum*	Catostomidae	y	benthic, pool	omnivore	intermediate	5	y
River redhorse	*Moxostoma carinatum*	Catostomidae	y	benthic, pool	invertivore	intolerant	3	y
Black redhorse	*Moxostoma duquesnei*	Catostomidae	y	benthic, pool	invertivore	intolerant	3	y
Golden redhorse	*Moxostoma erythrurum*	Catostomidae	y	benthic, pool	omnivore	intolerant	4	y
Shorthead redhorse	*Moxostoma macrolepidotum*	Catostomidae	y	benthic, pool	omnivore	intermediate	4	y
Yellow bullhead	*Ameiurus natalis*	Ictaluridae	y	pelagic	omnivore	tolerant	2	n
Brown bullhead	*Ameiurus nebulosus*	Ictaluridae	y	pelagic	omnivore	tolerant	3	n
Channel catfish	*Ictalurus punctatus*	Ictaluridae	y	pelagic	omnivore	intermediate	3	n
Margined madtom	*Noturus insignis*	Ictaluridae	y	pelagic	invertivore	intermediate	3	n
Brindled madtom	*Noturus miurus*	Ictaluridae	y	pelagic	invertivore	intermediate	1	n
Flathead catfish	*Pylodictis olivaris*	Ictaluridae	y	pelagic	predator	intermediate	3	n
Muskellunge	*Esox masquinongy*	Esocidae	n	pelagic	predator	intolerant	2	n
Rainbow trout	*Oncorhynchus mykiss*	Salmonidae	n	pelagic	predator	intolerant	1	n
Brown trout	*Salmo trutta*	Salmonidae	n	pelagic	predator	intolerant	1	n
Brook trout	*Salvelinus fontinalis*	Salmonidae	y	pelagic	predator	intolerant	2	n
Mottled sculpin	*Cottus bairdi*	Cottidae	y	riffle	invertivore	intermediate	2	n
Banded sculpin	*Cottus carolinae*	Cottidae	y	riffle	invertivore	intermediate	2	n
White bass	*Morone chrysops*	Percicthyidae	n	pelagic	predator	tolerant	2	y
Rock bass	*Ambloplites rupestris*	Centrarchidae	y	pelagic	predator	intermediate	2	n
Redbreast sunfish	*Lepomis auritus*	Centrarchidae	y	pelagic	predator	intermediate	2	n

Table 6. Metric scoring criteria for fish species collected in the Kanawha River Basin—*Continued*

Name	Scientific name	Family	Native	Habitat	Feeding habit	Tolerance	Reproductive age (years)	Simple lithophil
Green sunfish	*Lepomis cyanellus*	Centrarchidae	y	pelagic	predator	tolerant	1	n
Pumpkinseed	*Lepomis gibbosus*	Centrarchidae	y	pelagic	predator	intermediate	1	n
Bluegill	*Lepomis macrochirus*	Centrarchidae	y	pelagic	invertivore	tolerant	1	n
Longear sunfish	*Lepomis megalotis*	Centrarchidae	y	pelagic	invertivore	intermediate	2	n
Smallmouth bass	*Micropterus dolomieu*	Centrarchidae	y	pelagic	predator	intermediate	2	n
Spotted bass	*Micropterus punctulatus*	Centrarchidae	n	pelagic	predator	intermediate	2	n
Largemouth bass	*Micropterus salmoides*	Centrarchidae	y	pelagic	predator	intermediate	2	n
Greenside darter	*Etheostoma blennioides*	Percidae	y	riffle	invertivore	intolerant	2	n
Rainbow darter	*Etheostoma caeruleum*	Percidae	y	riffle	invertivore	intolerant	1	y
Bluebreast darter	*Etheostoma camurum*	Percidae	y	riffle	invertivore	intolerant	2	n
Fantail darter	*Etheostoma flabellare*	Percidae	y	riffle	invertivore	intermediate	2	n
Johnny darter	*Etheostoma nigrum*	Percidae	y	riffle	invertivore	intermediate	1	n
Candy darter	*Etheostoma osburni*	Percidae	y	riffle	invertivore	intolerant	2	y
Variegate darter	*Etheostoma variatum*	Percidae	y	riffle	invertivore	intermediate	2	n
Banded darter	*Etheostoma zonale*	Percidae	y	riffle	invertivore	intolerant	1	n
Yellow perch	*Perca flavescens*	Percidae	n	pelagic	predator	intermediate	3	n
Logperch	*Percina caprodes*	Percidae	y	riffle	invertivore	intermediate	2	y
Appalachia darter	*Percina gymnocephala*	Percidae	y	riffle	invertivore	intolerant	2	y
Sharpnose darter	*Percina oxyrhynchus*	Percidae	y	riffle	invertivore	intermediate	1	y
Roanoke darter	*Percina roanoka*	Percidae	y	riffle	invertivore	intermediate	2	y
Dusky darter	*Percina sciera*	Percidae	y	riffle	invertivore	intermediate	2	y
Sauger	*Stizostedion canadense*	Percidae	n	pelagic	predator	intermediate	2	y
Freshwater drum	*Aplodinotus grunniens*	Sciaenidae	y	pelagic	invertivore	intermediate	4	n

green sunfish are fairly sensitive to acidification, and were absent from acidic streams in western Pennsylvania (Earle and Callaghan, 1998). In northern West Virginia and western Pennsylvania, where acidification caused by coal-mine drainage is a disturbance of primary concern, green sunfish may be considered an intermediate rather than tolerant species. Brook trout, on the other hand, are extremely intolerant of high temperature and low dissolved-oxygen concentration, but are moderately tolerant to acidification. Many species that have a wide range with a variety of environmental conditions may be tolerant of disturbance in the part of their range where climatic conditions are optimal, but sensitive to disturbance at the edge of their range.

Like assignment of tolerance values, assignment of fish species to trophic guild (functional group of fish or other organisms that eat the same type of food, collected from the same type of habitat) has been inconsistent among investigators. This study used tolerance values given by Halliwell and others (1999), trophic guild classifications given by Goldstein and Simon (1999), and reproductive guild classifications given by Smogor and Angermeier (1999b), and referred to Jenkins and Burkhead (1994) or Etnier and Starnes (1993) for information on those species not discussed in the first three sources.

Metric scoring criteria are shown in table 6. Typically, when a multimetric index such as the IBI is used, sites are given numeric scores corresponding to poor, average, or good for each metric; these scores are calibrated through comparison to a set of reference sites. A regional multimetric index calibrated for NAWQA collection methods was unavailable, and a set of reference sites that were representative of the different environmental settings in the basin could not be sampled. Instead, for each metric, the standing of the sites relative to each other and environmental factors influencing the sites' rankings are discussed. This approach allows comparison only within the set of sites sampled, and does not support classifying sites relative to reference conditions. Furthermore, the set of sites represented streams differing in important ways other than the degree of disturbance, so the same metrics could not be applied to all sites throughout the basin. Instead, sites were stratified by size and metrics were applied describing functional aspects of the fish community to this stratification. Also, sites were stratified by drainage system and metrics describing structural aspects of the fish community were applied to this stratification.

Fish Metrics and Environmental Factors

For each site, 22 metrics were calculated that describe fish characteristics that have recently proved useful in assessing water quality near the Kanawha River Basin (table 7; Smogor and Angermeier,1999a, 1999b; Angermeier and others, 2000). Because Jaccard Similarity analysis had shown high within-stream variability at one of the multi-year, multi-reach sites in this study, only metrics with low within-stream variability relative to variability at all sites were considered appropriate for this data set. Effects from two additional characteristics, stream size and zoogeography, seemed capable of masking basin-scale land-use effects. Metrics were examined for response to these confounders.

Within-stream variability in fish metrics was assessed using the multi-year, multi-reach data. The standard deviations of metric scores from all primary reaches (no more than one reach per site) were compared to the standard deviations of the same metrics within each of the three multi-year, multi-reach sites (table 8). If the standard deviation of metric scores within one or more multi-year, multi-reach sites exceeded the overall standard deviation for that metric, the metric was considered too variable to use to classify sites. Four of the metrics we tested were more variable within one or more sites than among all sites; a fifth metric was nearly as variable within two sites as among all sites, and it was not used, either. Three were reproductive metrics: simple lithophilic species (species requiring clean, rocky substrate to successfully spawn), simple lithophilic species normalized by the logarithm of drainage area (logDA), and percentage of simple lithophilic species. The other two were among the most widely used metrics in IBI applications: sucker species richness and percentage of fish with external DELT anomalies, or deformities, erosion, lesions, or raised growths (apparent tumors).

Of these metrics, the percentage of fish with DELT anomalies was the most variable within stream segments, and standard deviation at two sites exceeded overall standard deviation. DELT anomalies generally are used as indicators of toxic materials in streams (Karr and Chu, 1999). No correlations were found between DELT anomalies and any of the toxic materials sampled in bed sediment, although concentrations of PAH's, nickel, chromium, and zinc all exceeded guidelines at some sites (Paybins and others, 2001). Dioxin, not sampled in this study, is an important con-

Table 7. Fish-community metrics at sites within the Kanawha River Basin

[logDA, common logarithm of drainage area; DELT, deformities, erosion, lesions, and tumors; collection number is given in parentheses]

Site	Total fish	Species richness	Species richness, divided by logDA	Number of darter and sculpin species	Number of darter and sculpin species, divided by logDA	Number of sucker species	Number of sucker species, divided by logDA
Reed Creek at Grahams Forge, Va. (1)	1,851	21	8.8	2	0.84	2	0.84
Reed Creek at Grahams Forge, Va. (2)	1,259	22	9.2	3	1.25	2	.84
Reed Creek at Grahams Forge, Va. (3)	2,585	25	10.4	2	.84	2	.84
Reed Creek at Grahams Forge, Va. (4)	1,338	21	8.8	2	.84	2	.84
Little River at Graysontown, Va.	1,531	27	10.9	6	2.42	1	.4
New River at Glen Lyn, Va.	1,794	25	7	5	1.4	1	.28
Bluestone River near Spanishburg, W.Va.	492	16	7	1	.43	2	.87
Little Bluestone River near Jumping Branch, W.Va.	1,071	6	4.2	1	.7	1	.7
Second Creek near Second Creek, W.Va.	2,011	20	10.5	5	2.62	2	1.05
New River at Thurmond, W.Va.	1,749	27	7.1	6	1.57	1	.26
Mill Creek near Hopewell, W.Va.	373	13	9.6	3	2.22	1	.74
Williams River at Dyer, W.Va. (1)	142	13	6.2	5	2.37	1	.47
Williams River at Dyer, W.Va. (2)	264	15	7.1	6	2.85	1	.47
Williams River at Dyer, W.Va. (3)	148	15	7.1	5	2.37	2	.95
Williams River at Dyer, W.Va. (4)	156	15	7.1	7	3.32	0	0
Sewell Creek at East Rainelle, W.Va.	920	12	7.5	1	.62	1	.62
Miller Creek at Nallen, W.Va.	212	8	8.5	2	2.12	0	0
Peters Creek near Lockwood, W.Va.	897	13	8.1	1	.62	1	.62
Kanawha River below Kanawha Falls, W.Va.	731	29	7.4	8	2.04	6	1.53
Kellys Creek at Cedar Grove, W.Va.	596	20	14.5	3	2.17	2	1.45
Laurel Fork near Hacker Valley, W.Va.	188	12	11.3	3	2.83	1	.94
Birch River at Boggs, W.Va.	859	10	8.2	2	1.65	2	1.65
Blue Creek at Sanderson, W.Va.	245	17	10	6	3.53	1	.59
Sandlick Creek near Arnett, W.Va.	275	11	8.5	3	2.31	2	1.54
Clear Fork at Whitesville, W.Va. (1)	1,311	24	13.3	7	3.89	2	1.11
Clear Fork at Whitesville, W.Va. (2)	966	22	12.2	5	2.78	3	1.67
Clear Fork at Whitesville, W.Va. (3)	769	22	12.2	6	3.34	2	1.11
Clear Fork at Whitesville, W.Va. (4)	854	20	11.1	7	3.89	1	.56
Spruce Laurel Fork at Clothier, W.Va.	310	16	10.6	5	3.33	1	.67
Kanawha River above Winfield Dam, W.Va.	946	17	4.2	0	0	5	1.23

Table 7. Fish-community metrics at sites within the Kanawha River Basin—*Continued*

Site	Number of native minnow species	Number of native minnow species, divided by logDA	Omnivorous individuals, as a percentage	Predatory individuals, as a percentage	Water column invertivorous individuals, as a percentage	Number of water column invertivorous species	Number of water column invertivorous species, divided by logDA
Reed Creek at Grahams Forge, Va. (1)	9	3.76	0.09	0.15	0.09	6	2.51
Reed Creek at Grahams Forge, Va. (2)	14	5.85	.17	.22	.07	3	1.25
Reed Creek at Grahams Forge, Va. (3)	10	4.18	.37	.11	.08	6	2.51
Reed Creek at Grahams Forge, Va. (4)	7	2.93	.08	.14	.09	5	2.09
Little River at Graysontown, Va.	14	5.65	.36	.11	.15	7	2.83
New River at Glen Lyn, Va.	10	2.8	.32	.08	.43	6	1.68
Bluestone River near Spanishburg, W.Va.	6	2.61	.03	.91	.04	2	.87
Little Bluestone River near Jumping Branch, W.Va.	4	2.81	.19	0	.2	0	0
Second Creek near Second Creek, W.Va.	9	4.72	.03	.04	.3	5	2.62
New River at Thurmond, W.Va.	14	3.66	.19	.08	.18	6	1.57
Mill Creek near Hopewell, W.Va.	7	5.18	.76	.03	.09	2	1.48
Williams River at Dyer, W.Va. (1)	4	1.9	.26	.15	.43	3	1.42
Williams River at Dyer, W.Va. (2)	4	1.9	.2	.25	.3	3	1.42
Williams River at Dyer, W.Va. (3)	4	1.9	.41	.05	.33	3	1.42
Williams River at Dyer, W.Va. (4)	5	2.37	.21	.11	.31	3	1.42
Sewell Creek at East Rainelle, W.Va.	7	4.37	.83	.07	.05	3	1.87
Miller Creek at Nallen, W.Va.	3	3.18	.43	.05	.38	1	1.06
Peters Creek near Lockwood, W.Va.	8	4.99	.41	.1	.14	2	1.25
Kanawha River below Kanawha Falls, W.Va.	10	2.55	.06	.08	.4	5	1.27
Kellys Creek at Cedar Grove, W.Va.	12	8.68	.23	.04	.27	5	3.62
Laurel Fork near Hacker Valley, W.Va.	6	5.66	.24	.02	.47	1	.94
Birch River at Boggs, W.Va.	4	3.3	.37	0	.22	0	0
Blue Creek at Sanderson, W.Va.	8	4.71	.54	0	.18	5	2.94
Sandlick Creek near Arnett, W.Va.	6	4.62	.36	0	.41	2	1.54
Clear Fork at Whitesville, W.Va. (1)	11	6.12	.28	.02	.39	5	2.78
Clear Fork at Whitesville, W.Va. (2)	12	6.67	.14	.04	.46	4	2.22
Clear Fork at Whitesville, W.Va. (3)	11	6.12	.18	.07	.34	4	2.22
Clear Fork at Whitesville, W.Va. (4)	10	5.56	.16	.07	.41	4	2.22
Spruce Laurel Fork at Clothier, W.Va.	7	4.66	.08	.03	.45	3	2
Kanawha River above Winfield Dam, W.Va.	1	.25	.09	.03	.07	4	.98

Table 7. Fish-community metrics at sites within the Kanawha River Basin—*Continued*

Site	Tolerant individuals as a percentage	Number of intolerant species	Number of intolerant species, divided by logDA	Individuals with DELT anomalies as a percentage	Number of simple lithophilic species	Number of simple lithophilic species, divided by logDA	Number of species reaching repro-ductive maturity at age 3 or later	Number of species reaching reproduc-tive matu-rity at age 3 or later, divided by logDA
Reed Creek at Grahams Forge, Va. (1)	0.58	2	0.84	0.01	7	2.93	7	2.93
Reed Creek at Grahams Forge, Va. (2)	.39	1	.42	.02	9	3.76	6	2.51
Reed Creek at Grahams Forge, Va. (3)	.37	3	1.25	.01	8	3.34	6	2.51
Reed Creek at Grahams Forge, Va. (4)	.58	2	.84	.02	6	2.51	6	2.51
Little River at Graysontown, Va.	.26	3	1.21	.01	11	4.44	5	2.02
New River at Glen Lyn, Va.	.04	3	.84	.01	8	2.24	7	1.96
Bluestone River near Spanishburg, W.Va.	.03	2	.87	.03	4	1.74	3	1.3
Little Bluestone River near Jumping Branch, W.Va.	.73	1	.7	.02	3	2.11	1	.7
Second Creek near Second Creek, W.Va.	.46	3	1.57	.02	7	3.67	4	2.1
New River at Thurmond, W.Va.	.06	3	.78	.02	11	2.88	3	.78
Mill Creek near Hopewell, W.Va.	.27	2	1.48	.02	7	5.18	2	1.48
Williams River at Dyer, W.Va. (1)	.08	4	1.9	0	6	2.85	3	1.42
Williams River at Dyer, W.Va. (2)	.01	5	2.37	.01	6	2.85	2	.95
Williams River at Dyer, W.Va. (3)	.07	4	1.9	.03	5	2.37	3	1.42
Williams River at Dyer, W.Va. (4)	.08	5	2.37	.06	6	2.85	4	1.9
Sewell Creek at East Rainelle, W.Va.	.86	2	1.25	.04	5	3.12	1	.62
Miller Creek at Nallen, W.Va.	.82	2	2.12	.05	2	2.12	0	0
Peters Creek near Lockwood, W.Va.	.35	1	.62	.04	5	3.12	2	1.25
Kanawha River below Kanawha Falls, W.Va.	.02	6	1.53	.02	12	3.06	9	2.29
Kellys Creek at Cedar Grove, W.Va.	.45	4	2.89	.03	7	5.07	4	2.89
Laurel Fork near Hacker Valley, W.Va.	.39	5	4.71	.03	5	4.71	2	1.89
Birch River at Boggs, W.Va.	.74	1	.82	.01	3	2.47	3	2.47
Blue Creek at Sanderson, W.Va.	.13	3	1.76	.04	5	2.94	2	1.18
Sandlick Creek near Arnett, W.Va.	.79	2	1.54	.05	5	3.85	2	1.54
Clear Fork at Whitesville, W.Va. (1)	.22	6	3.34	.01	4	2.22	3	1.67
Clear Fork at Whitesville, W.Va. (2)	.13	5	2.78	.02	9	5.01	3	1.67
Clear Fork at Whitesville, W.Va. (3)	.08	5	2.78	.03	9	5.01	5	2.78
Clear Fork at Whitesville, W.Va. (4)	.15	5	2.78	.06	10	5.56	2	1.11
Spruce Laurel Fork at Clothier, W.Va.	.42	5	3.33	.04	6	3.99	1	.67
Kanawha River above Winfield Dam, W.Va.	.82	1	.25	.03	6	1.47	9	2.21

Table 8. Standard deviations of metrics among all sites and within multi-year, multi-reach sites, Kanawha River Basin

[DELT, deformities, erosion, lesions, and tumors; bold type indicates a value from a single site exceeds the value for all sites]

Metric	Standard deviation			
	All sites	Reed Creek at Grahams Forge, Va.	Williams River at Dyer, W.Va.	Clear Fork at Whitesville, W.Va.
Taxa richness metrics, unadjusted				
Species richness	6.63	1.89	1.00	1.63
Darter and sculpin species	2.29	.50	.96	.96
Minnow species	3.47	2.94	.50	.82
Sucker species	1.38	0.00	.82	.82
Sunfish species	2.00	.82	.58	.50
Simple lithophilic species	2.65	1.29	.50	**2.71**
Late maturing species	2.56	.50	.82	1.26
Intolerant species	1.58	.82	.58	.50
Taxa richness metrics, adjusted by drainage area				
Species richness	2.60	.79	.47	.91
Darter and sculpin species	1.07	.21	.45	.53
Minnnow species	1.77	1.23	.24	.45
Sucker species	.46	0.00	.39	.45
Sunfish species	.81	.34	.27	.28
Simple lithophilic species	1.07	.54	.24	**1.51**
Late maturing species	.77	.21	.39	.70
Intolerant species	1.11	.34	.27	.28
Proportional metrics				
Proportion of simple lithophilic individuals	.18	.05	.17	.19
Proportion of benthic invertivores	.19	.06	.08	.07
Proportion of predators	.19	.05	.08	.03
Proportion of omnivores	.22	.13	.10	.07
Proportion of individuals with DELTs	.01	.01	**.03**	**.02**
Proportion of tolerant individuals	.30	.11	.04	.06

taminant in bed sediment in the Kanawha River; it may be present there in sufficient concentrations to cause toxic effects to fish, but it probably is not widespread throughout the basin (TetraTech, Inc., 2000), and it is unlikely that it or another unsampled toxic substance would correlate closely with DELT anomalies. The high variance of DELT anomalies among stream reaches suggests that factors such as reach-level geomorphology affect species composition or the location of depositional areas where toxic materials accumulate, which in turn affects the distribution of DELT anomalies. The other four metrics with high within-stream variability are all expected to be affected by reach-level habitat. Simple lithophils are those species that require clean, rocky stream bottoms to reproduce, and suckers are pool-dwelling benthic species; both groups are susceptible to sedimentation, which varies as a result of geomorphic differences among stream reaches.

Many attributes of streams, including fish communities, are well known to change along a continuum of stream size (Vannote and others, 1980). Some attributes of the fish communities sampled in this study were dominated by stream size. Stream size was measured using drainage area. Streams were divided into three groups, small (< 20 mi^2), medium (between 20 and 300 mi^2), and large (> 3,700 mi^2; no sites between 300 and 3,700 mi^2 were sampled). Two of the small streams were reference streams; one drained a state park (Laurel Fork near Hacker Valley, W.Va.) and the other drained an unmined, uninhabited, forested basin (Miller Creek at Nallen, W.Va.). The other two small streams drained basins affected by residential use, low-intensity agriculture, and highways; one was lightly mined (Birch River at Boggs, W.Va.; 8.16 thousand tons/mi^2, 1980–95) and the other was heavily mined (Sandlick Creek near Arnett, W.Va.; 406 thousand tons/mi^2, 1980-95). Medium streams drained basins that were disturbed by human activities across a broad gradient of intensity, ranging from forested or low-intensity agricultural basins, to heavily mined basins with heavy residential and transportation effects. Large streams generally contained low concentrations of most chemical constituents. All had complex habitat structure except for the Kanawha River above Winfield Dam, which is in backwater from a navigation dam.

Total species and number of species from the selected taxonomic groups increased with increases in drainage area, despite basin land uses and other indicators of environmental quality. Because the site network included sites draining areas ranging from less than 10 mi^2 to more than 10,000 mi^2, taxa richness metrics were normalized by logDA. This approach has been used successfully in regulatory stream assessments in North Carolina, although no streams under consideration there drained areas as large as some streams considered in this study (North Carolina Department of Environment, Health and Natural Resources, 1997). Normalizing metrics by logDA is a variation of the more widely used approach of adjusting criteria for assigning good, fair, or poor scores to a sample based on visually fitting trendlines to species richness values plotted at a logarithmic scale as a function of drainage area (Yoder and Rankin, 1999). In general, unadjusted taxa richness metrics were higher in large streams over medium and small streams, but drainage-area normalized metrics were higher in small streams than medium or large streams (fig. 10). The exception was the sunfish-species metric, which was lowest for small streams even when normalized by drainage area. The other taxa-richness metrics were not significantly different among stream size classes.

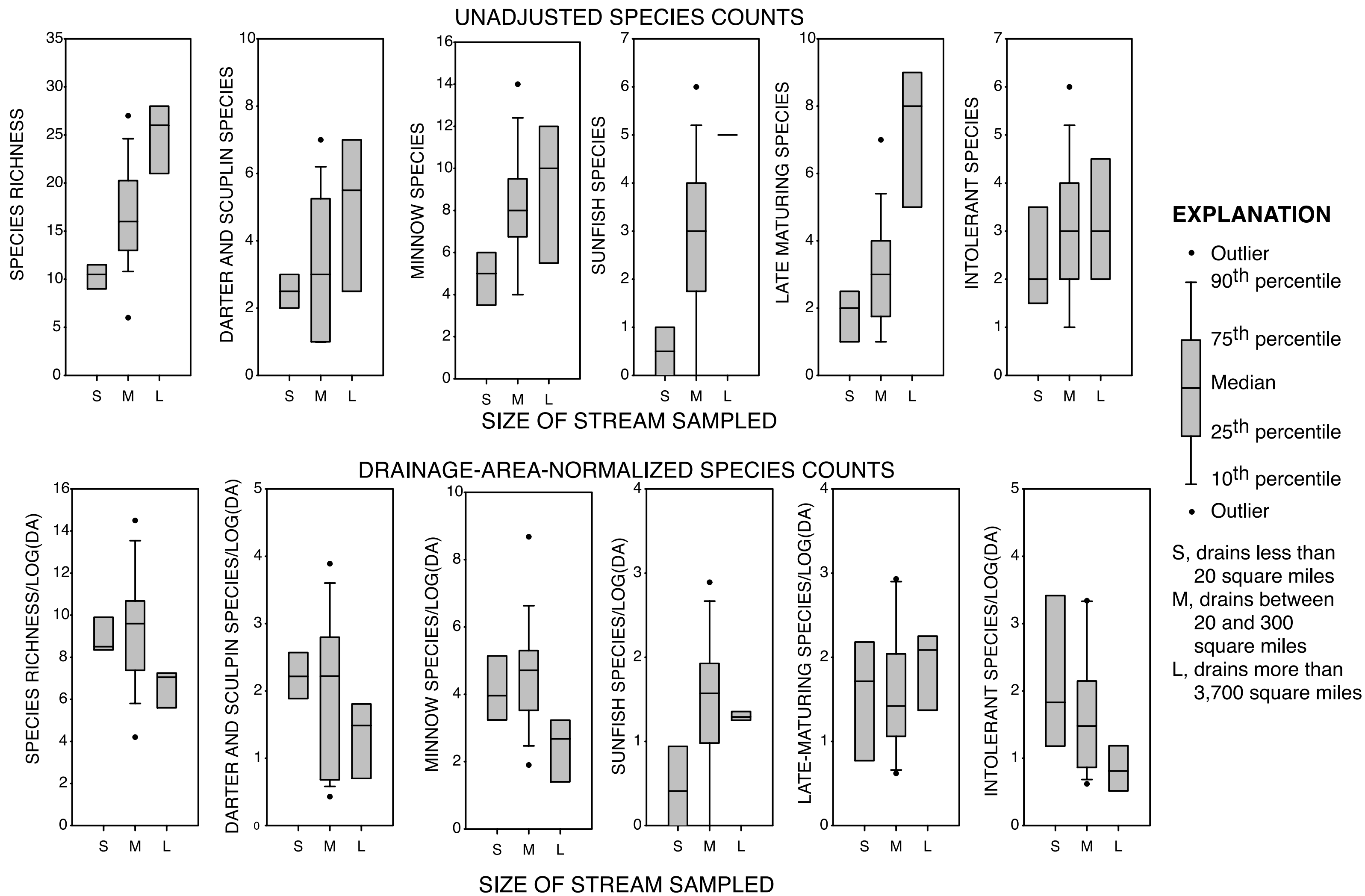


Figure 10. Stream size strongly affects metrics based on counts of species. When adjusted species counts are compared, large streams usually score highest, followed by medium streams and then small streams. When species counts are normalized by the common logarithm of the drainage area, small and medium streams usually score higher than large streams. An exception is the number of sunfish, which were absent from several of the smallest streams. Disturbance is expected to decrease all metrics.

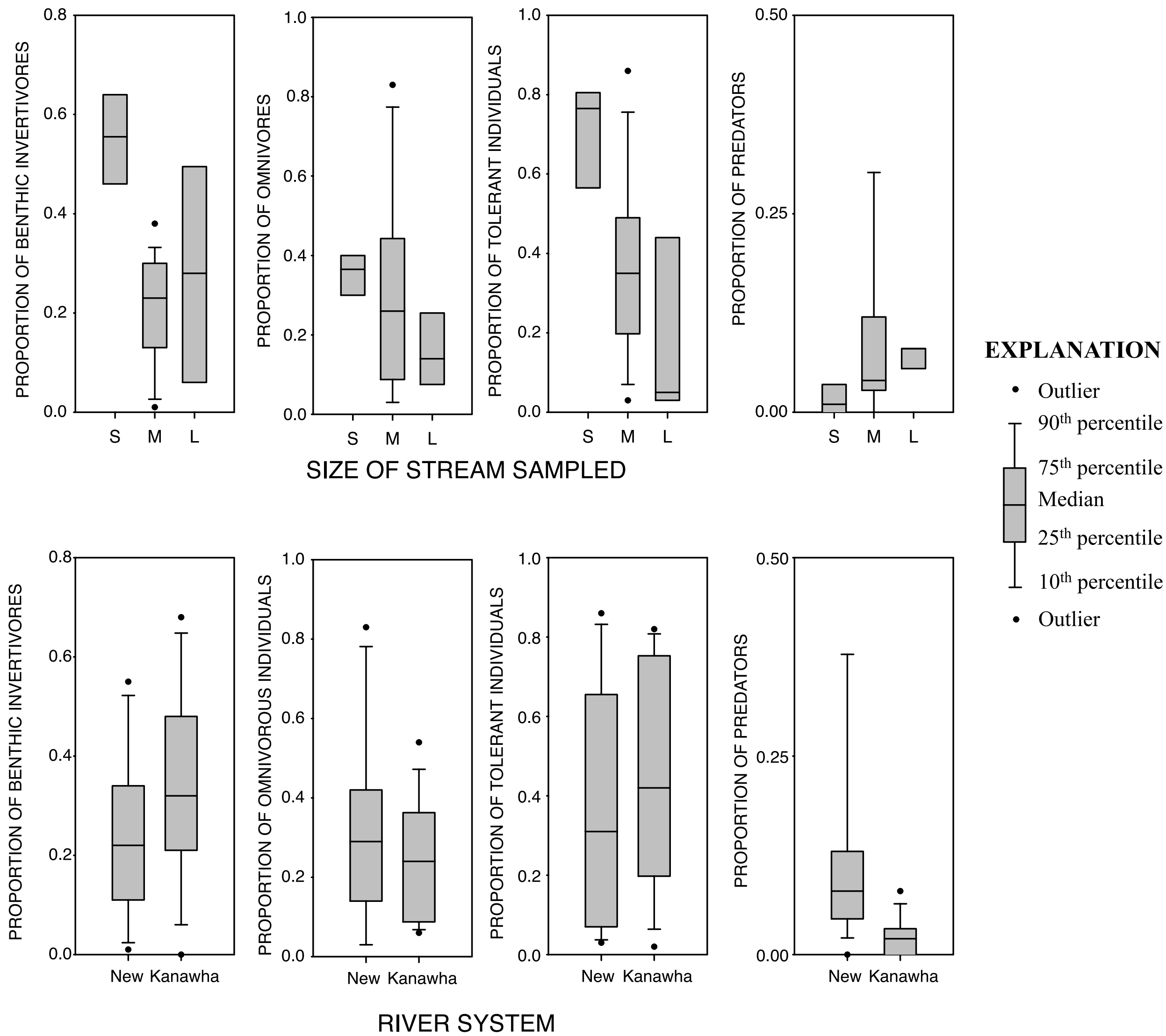


Figure 11. Small streams consistently scored lowest in proportional metrics, but basin effects were varied. Except for proportion of benthic invertivores, large streams had the best proportional metric scores, and medium sites were intermediate between large and small streams. New River streams contained a higher proportion of predators, but basins were similar otherwise. (Bluestone River at Spanishburg, a medium site in the New River System, contained 91-percent predators and is not plotted.)

As described by the River Continuum Concept (Vannote and others, 1980), tolerance and trophic-status metrics tended to be lower for small streams than for medium and large streams, and, therefore, inappropriate for comparing the quality of small streams to large streams. Fish communities from the small streams were dominated by blacknose dace and creek chubs, which are both tolerant, omnivorous species. As a result, the proportions of tolerant and omnivorous individuals in small streams were greater than in medium and large streams (fig. 11). Proportions of tolerant and omnivorous species are thought to increase in response to disturbance. Blacknose dace and creek chubs may not be reliable indicators of disturbance in small streams, although they probably are for larger streams. Small streams, even those that drain pristine areas, are naturally unstable environments. During droughts, small streams may dry up, and under normal flow conditions, small streams fluctuate more in flow and temperature than larger streams. Typical small-stream fish such as blacknose dace and creek chubs have evolved to tolerate these conditions. In contrast, a metric thought to decrease in response to disturbance, proportion of the community as benthic invertivores, was highest in small streams and about the same in medium and large streams (fig. 11). Benthic invertivores are a trophic guild that includes darters, sculpins, suckers, and a few minnows.

Comparison between the New and Kanawha River System sites was more problematic than comparison among different size classes of sites. The New River System naturally lacks native species, both total species and within the minnow, sucker, sunfish, and darter families (Jenkins and Burkhead, 1994). Of these groups, sunfish are the only popular game fish and the only group that has been systematically introduced throughout the system. An original premise of this study was that direct comparison between the two systems would be possible, because the large number of introduced fish species in the New River has increased its total species count to 90, roughly similar to the 118 species of the Kanawha River System. Although many species have been introduced to the New River System, the distribution of most introduced species and many native species is spotty and inconsistent, and varies throughout the system.

Fewer fish species were collected from sites in the New River System than from sites in the Kanawha River System. With the exception of minnow and sunfish species, medians of all taxa richness metrics were lower in the New than the Kanawha River System (fig. 12). Based on stream size and chemical and biological measures of environmental quality, taxa richness metrics should have been higher in the New River System than the Kanawha River System (fig. 13). Differences between the two systems in taxa richness metrics were generally not statistically significant, but they were consistent among metrics and inconsistent with other measures of environmental quality and therefore not used to compare sites between the two systems. However, the medians and ranges of most proportional metrics were about the same for the New and Kanawha River Systems, consistent with other environmental indicators (fig. 11). The exception was proportion of the community as predators, which was higher in New River sites. The proportion of predators is probably higher in New River sites than Kanawha River sites because most of the predators in the basin were sunfish. Sunfish have been intentionally, systematically introduced throughout the New River System, and their greater abundance at New River sites represents environmental conditions that are more favorable.

Site Rankings

Sites were stratified by size and ranked in functional or proportional metrics within the size classes. Sites then were stratified by river system and ranked in species compostition metrics within the New River and Kanawha River System groups. In general, few sites had consistently good or bad ranks in different metrics under either stratification, largely because there was a relatively small overall range of metric scores.

Among the small sites, Laurel Fork near Hacker Valley had the best score in one of the four functional metrics, and had good scores in all the others (table 9). Laurel Fork drains a state park and drains a basin that has never been mined. Some of the lowest concentrations of undesirable constituents dissolved in water or deposited in sediment measured in the study were at this site, and most invertebrate community metrics calculated for this site showed it to be among the best in the study (Ward and others, 1999; Chambers and Messinger, 2001). Differences in rankings among the other five small sites were probably not significant. Among the medium sites, Sewell Creek at East Rainelle had poor scores in all four proportional metrics, because of poor reach-level habitat. The sampling reach at this site has been straightened and regularly dredged as a flood-control measure, and both banks are mowed regularly. Clear Fork at Whitesville, Bluestone River near Spanishburg, Williams River at Dyer, Little River at Graysontown, Spruce Laurel Fork at Clothier, and Second Creek near Second Creek all had good scores in most of the four proportional metrics; these sites apparently had little in common, either in terms of land use, physiography, chemistry, or habitat structure. Peters Creek near Lockwood, Kellys Creek at Cedar Grove, and Blue Creek near Sanderson had relatively poor scores in two or three proportional metrics. These sites had been heavily mined, although two of the typically high-scoring sites (Clear Fork and

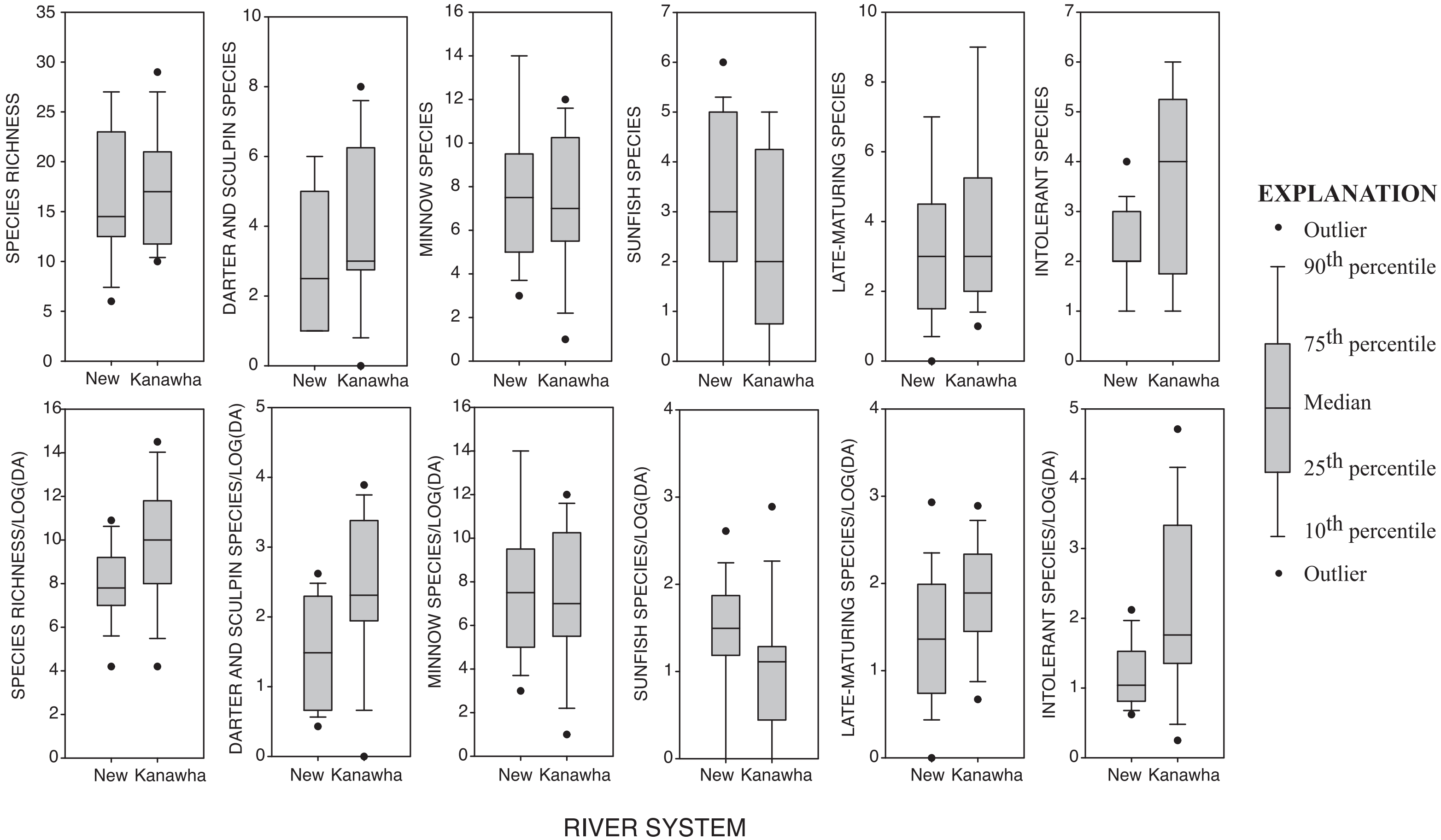


Figure 12. Taxa-richness based metrics are generally greater in collections from the Kanawha River System than in collections from the New River System. Number of sunfish species is the exception to the general pattern; sunfish, popular game fish, are the only taxonomic group that have been systematically introduced to streams throughout the New River System. Median number of minnow species (adjusted by stream size) is larger in the New River System; many minnows are commonly used for bait.

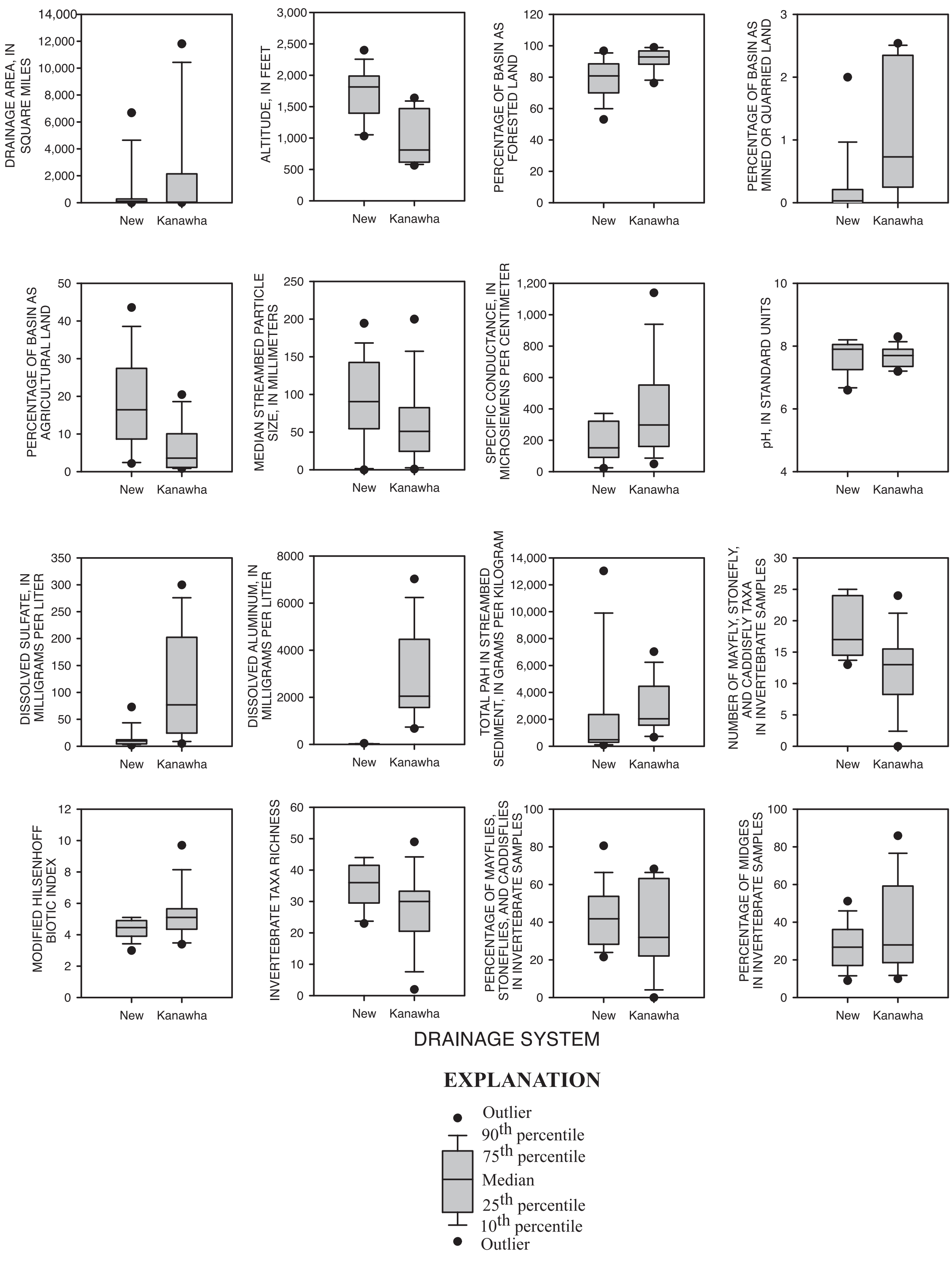


Figure 13. Habitat, land cover, and water-chemistry characteristics and invertebrate metrics generally indicated that fish communities at New River System sites would be more diverse than at Kanawha River System sites. Exceptions include drainage area, elevation, and forest cover.

Table 9. Rankings of small, medium, and large sites in the Kanawha River Basin in proportions of fish meeting four criteria

[Smallest numbers indicate most favorable conditions, whether or not the metric is expected to increase or decrease with disturbance. Collection numbers, in parentheses, are explained in table 4]

Site	Tolerant individuals	Omnivores	Predators	Benthic invertivores
Small				
Little Bluestone River near Jumping Branch, W.Va.	3	1	5	5
Mill Creek near Hopewell, W.Va.	1	6	2	6
Miller Creek at Nallen, W.Va.	6	5	1	3
Laurel Fork near Hacker Valley, W.Va.	2	2	3	1
Birch River at Boggs, W.Va.	4	4	4	4
Sandlick Creek near Arnett, W.Va.	5	3	5	2
Medium				
Reed Creek at Grahams Forge, Va. (1)	19	5	5	16
Reed Creek at Grahams Forge, Va. (2)	13	16	8	18
Reed Creek at Grahams Forge, Va. (3)	14	8	3	10
Reed Creek at Grahams Forge, Va. (4)	18	4	6	17
Little River at Graysontown, Va.	11	15	7	5
Bluestone River near Spanishburg, W.Va.	2	2	1	20
Second Creek near Second Creek, W.Va.	17	1	16	11
Williams River at Dyer, W.Va. (1)	6	13	4	6
Williams River at Dyer, W.Va. (2)	1	10	2	14
Williams River at Dyer, W.Va. (3)	3	17	14	15
Williams River at Dyer, W.Va. (4)	5	11	9	13
Sewell Creek at East Rainelle, W.Va.	20	20	12	19
Peters Creek near Lockwood, W.Va.	12	18	10	7
Kellys Creek at Cedar Grove, W.Va.	16	12	17	12
Blue Creek at Sanderson, W.Va.	8	19	20	8
Clear Fork at Whitesville, W.Va. (1)	10	14	19	9
Clear Fork at Whitesville, W.Va. (2)	7	6	15	3
Clear Fork at Whitesville, W.Va. (3)	4	9	11	1
Clear Fork at Whitesville, W.Va. (4)	9	7	13	2
Spruce Laurel Fork at Clothier, W.Va.	15	3	18	4
Large				
New River at Glen Lyn, W.Va.	2	4	3	3
New River at Thurmond, W.Va.	3	3	2	1
Kanawha River below Kanawha Falls, W.Va.	1	1	1	2
Kanawha River above Winfield Dam, W.Va.	4	2	4	4

Spruce Laurel Fork) also had been heavily mined. Among the large sites, Kanawha River below Kanawha Falls scored best in three of the four metrics, and Kanawha River above Winfield Dam ranked worst in three metrics. Kanawha River above Winfield Dam differs from the other large sites by being in backwater from a navigation dam, being regularly dredged, and completely lacking riffle or shoal habitat.

Bluestone River near Spanishburg was unique in having the best or second best score in proportions of tolerant individuals, omnivores, and predators, and the worst score in proportion of benthic invertivores (table 9). This site had very short, poorly developed riffles, and long pools with abundant macrophyte growth. The fish community was dominated by rock bass and redbreast sunfish; both species were collected from the macrophyte beds. The good score at this site in three of the four metrics is somewhat deceptive, because of the unbalanced composition of the fish community.

In grouping sites for ranking, two exceptions were made to the grouping of sites by size used in the previous section. Mill Creek near Hopewell, W.Va. (22.4 mi^2), and Little Bluestone River near Jumping Branch, W.Va. (26.4 mi^2), were included in the group of small sites. These were two of the smallest of the medium sites in terms of drainage area as well as stream width and depth; also, TWINSPAN grouped them with small sites instead of medium sites. When these two sites were included among medium sites, they ranked among the worst in most metrics, but their ranks among small sites ranged from the best to the worst of the four proportional metrics (table 9).

In structural or species composition metrics, Little River at Graysontown, Second Creek near Second Creek, Reed Creek at Grahams Forge, and Williams River at Dyer consistently scored among the best among New River System sites (table 10). Sewell Creek at East Rainelle, Bluestone River near Spanishburg, and Little Bluestone River near Jumping Branch scored consistently among the worst New River System sites in most structural metrics. Among Kanawha River sites, Clear Fork at Whitesville, Kellys Creek at Cedar Grove, and Laurel Fork near Hacker Valley scored among the best sites in several structural metrics, while Kanawha River above Winfield Dam, Sandlick Creek near Arnett, and Birch River at Boggs ranked consistently among the worst sites in most structural metrics.

No single fish-community metric was strongly correlated with any invertebrate-community metric, and site rankings differed in fish-community and invertebrate-community metrics. To a degree, it is expected for invertebrate and fish communities to respond to different disturbances, and therefore for metrics based on them to be useful in identifying different disturbances. No single fish-community metric was strongly correlated with any other measure of environmental quality, although several invertebrate community metrics were, at least within the coal synoptic study (Chambers and Messinger, 2001). This apparent difference in fish and invertebrate response to disturbance was probably an artifact of study design relative to the zoogeographic differences in the basin. The subset of fish-collection sites in the synoptic study appeared to be representative of environmental conditions in the entire set of invertebrate collection sites in that study (fig. 13). The fish-collection sites, however, were selected under the assumption that zoogeographic influence was, as with invertebrate-collection sites, at most a minor confounding factor; this proved not to be the case. When environmental stresses were considered relative to stream size within the two stream systems, some stresses were not well distributed. Although coal production at fish sites, for instance, was representative of the gradient of coal mining that was sampled at invertebrate sites, it was heavy at most medium Kanawha River System sites and light at most medium New River System sites (fig. 14*A,B*).

Fish Relative Abundance and Environmental Factors

A multivariate statistical approach was used to try to determine the most important aspects of the physical and chemical environment that affect fish communities. The abundances of fish taxa were related to environmental factors using canonical correspondence analysis (CCA). Results of CCA were meaningful only when subsets of the overall group of sites were

Table 10. Rankings of sites in the New and Kanawha River Systems in numbers of fish species in five categories

[Smallest numbers indicate most favorable conditions, whether or not the metric is expected to increase or decrease with disturbance]

Site	Adjusted by log (drainage area)		Unadjusted counts		
	Total species	Reproductively mature at age 3 or later	Darters and sculpins	Intolerant species	Insectivorous minnows
New River System					
Reed Creek at Grahams Forge, Va. (1)	6	1	11	10	8
Reed Creek at Grahams Forge, Va. (2)	3	2	11	5	7
Reed Creek at Grahams Forge, Va. (3)	5	2	9	16	1
Reed Creek at Grahams Forge, Va. (4)	6	2	11	10	11
Little River at Graysontown, Va.	1	6	2	5	2
New River at Glen Lyn, Va.	15	7	5	5	13
Bluestone River near Spanishburg, W.Va.	16	12	15	10	14
Little Bluestone River near Jumping Branch, W.Va.	18	16	15	16	12
Second Creek near Second Creek, W.Va.	2	5	5	5	5
New River at Thurmond, W.Va.	14	15	2	5	9
Mill Creek near Hopewell, W.Va.	4	9	9	10	3
Williams River at Dyer, W.Va. (1)	17	10	5	3	16
Williams River at Dyer, W.Va. (2)	11	14	2	1	16
Williams River at Dyer, W.Va. (3)	11	10	5	3	16
Williams River at Dyer, W.Va. (4)	11	8	1	1	15
Sewell Creek at East Rainelle, W.Va.	10	17	15	10	6
Miller Creek at Nallen, W.Va.	8	18	11	10	10
Peters Creek near Lockwood, W.Va.	9	13	15	16	4
Kanawha River System					
Kanawha River below Kanawha Falls, W.Va.	11	4	1	1	11
Kellys Creek at Cedar Grove, W.Va.	1	1	8	8	1
Laurel Fork near Hacker Valley, W.Va.	5	6	8	3	5
Birch River at Boggs, W.Va.	10	3	11	11	10
Blue Creek at Sanderson, W.Va.	8	10	4	9	7
Sandlick Creek near Arnett, W.Va.	9	9	8	10	9
Clear Fork at Whitesville, W.Va. (1)	2	7	2	1	3
Clear Fork at Whitesville, W.Va. (2)	3	7	6	3	2
Clear Fork at Whitesville, W.Va. (3)	3	2	4	3	3
Clear Fork at Whitesville, W.Va. (4)	6	11	2	3	6
Spruce Laurel Fork at Clothier, W.Va.	7	12	6	3	8
Kanawha River above Winfield Dam, W.Va.	12	5	12	11	12

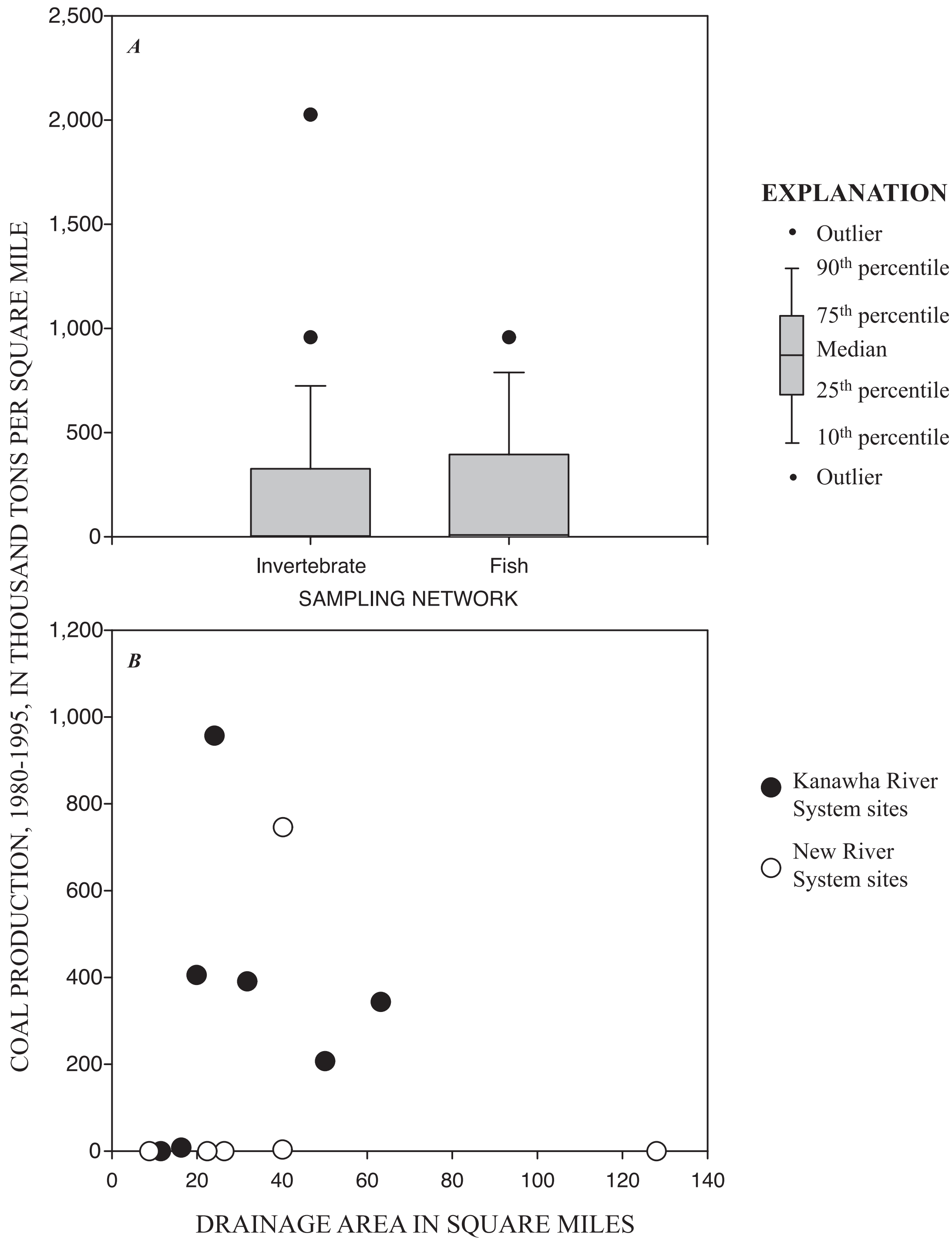


Figure 14. (*A*) The range of coal production among invertebrate and fish sites in the mining synoptic study was similar; median production in both groups of sites was small. (*B*) Most sites with coal production above the study median were in the Kanawha River System, where fish communities naturally contain more species than in the New River System, where larger sites draining unmined areas were located.

analyzed. Because of the effects of zoogeography and the lack of unmined, medium-sized streams in the coal-mining region, conclusions could not be made about the effects of coal mining on fish communities.

CCA was used to determine relations between fish abundances and environmental conditions in the basin. CCA is a multivariate ordination technique in which reciprocal averaging is used to relate species abundances to environmental variables, and classify sites along environmental axes, or calculated gradients of multiple variables (Gauch, 1982). Three premises of CCA are that (1) each species has an optimum of each environmental variable, (2) species are distributed according to the distribution of their optimum conditions, and (3) populations of each species are distributed with a single statistical mode relative to each environmental variable (ter Braak and Verdonshot, 1995). CCA is robust and can be used to classify sites in a meaningful way even when many of its assumptions are violated (Palmer, 1993). However, CCA is not able to properly place sites along environmental gradients when species distribution is affected strongly by something other than environmental gradients—such as barriers to movement, or lack of time for species newly introduced to an area to spread throughout the available habitat meeting their physiological needs (Palmer, 2000). Fish distribution in the Kanawha River Basin is strongly affected by Kanawha Falls and the numerous other barriers that prevent fish species, both native and introduced, from moving freely through the basin. The most-similar sites in a set are grouped by CCA; however, if species distributions are affected by factors other than environmental gradients, species-environment relations determined with CCA can be invalid or misleading (Palmer, 2000).

Species data as relative abundance were octave-transformed (Gauch, 1982). Concentration data for constituents in water were $\log_{10}$-transformed ($\log_{10}$ ([concentration in mg/L] + 1)) (Gauch, 1982; Palmer, 2000). Basin area as a percentage of land cover category or surficial geologic formation, or invertebrate metrics were not transformed (tables 11 and 12). As a test of ordination robustness, species abundance data were $\log_{10}$ or square-root transformed, ordinations were done, and these results were compared to the octave-transformed results (ter Braak and Smilauer, 1998). Although different transformations slightly changed the placement of sites along the environmental axes, the same environmental variables were of approximately equal relative importance when different transformations of species data were used.

Table 11. Land-cover characteristics of fish-community collection sites in the Kanawha River Basin, expressed as a percentage of basin area

[Data are from Multi-Resolution Land Characteristics Interagency Consortium, 1997

Site	Combined residential and urban	Mines, quarries, and disturbed land	Forest	Agriculture
Reed Creek at Grahams Forge, Va.	2.9	0.0	53.1	43.6
Little River at Graysontown, Va.	.2	.0	62.8	36.4
New River at Glen Lyn, Va.	1.7	.0	67.9	29.5
Bluestone River near Spanishburg, W.Va.	3.2	.5	80.7	14.3
Little Bluestone River near Jumping Branch, W.Va.	.1	.1	80.8	18.5
Second Creek near Second Creek, W.Va.	.1	.0	72.0	25.3
New River at Thurmond, W.Va.	1.5	.1	73.1	24.0
Mill Creek near Hopewell, W.Va.	.1	.0	88.7	9.6
Williams River at Dyer, W.Va.	.0	.0	96.8	2.2
Sewell Creek at East Rainelle, W.Va.	.2	.4	85.9	10.3
Miller Creek at Nallen, W.Va.	.2	.0	94.8	2.5
Peters Creek near Lockwood, W.Va.	.7	2.0	88.2	7.7
Kanawha River below Kanawha Falls, W.Va.	1.4	.3	76.3	20.5
Kellys Creek at Cedar Grove, W.Va.	.2	2.3	92.8	3.6
Laurel Fork near Hacker Valley, W.Va.	.9	.0	99.0	.8
Birch River at Boggs, W.Va.	.2	2.5	91.8	5.3
Blue Creek at Sanderson, W.Va.	.1	.0	98.6	.9
Sandlick Creek near Arnett, W.Va.	.3	.7	90.7	8.2
Clear Fork at Whitesville, W.Va.	.4	2.3	94.0	1.9
Spruce Laurel Fork at Clothier, W.Va.	.5	2.5	96.0	1.2
Kanawha River above Winfield Dam, W.Va.	1.6	.5	80.7	15.8

Table 12. Invertebrate community metrics for all reaches at fish community collection sites in the Kanawha River Basin

[EPT, Ephemeroptera, Plecoptera, and Trichoptera, or mayfly, stonefly, and caddisfly; MHBI, Modified Hilsenhoff Biotic Index; data are from Chambers and Messinger, 2000]

Site	Reach	EPT taxa (number)	MHBI	Taxa richness (number)	EPT proportion	Midge proportion	Scraper:shredder ratio
Reed Creek at Grahams Forge, Va.	A (1997)	15	4.5	30	42.9	51.2	0.42
Reed Creek at Grahams Forge, Va.	A (1998)	8	3.9	23	52.0	29.6	.28
Reed Creek at Grahams Forge, Va.	B	10	4.6	33	36.6	36.6	.45
Reed Creek at Grahams Forge, Va.	C	21	4.1	36	56.3	21.5	.42
Little River at Graysontown, Va.	A	25	4.8	44	45.7	33.0	.23
New River at Glen Lyn, Va.	A	16	5.0	29	21.5	33.2	.60
Bluestone River near Spanishburg, W.Va.	A	14	4.3	36	31.2	17.4	.74
Little Bluestone River near Jumping Branch, W.Va.	A	21	4.4	43	35.1	16.5	.24
Second Creek near Second Creek, W.Va.	A	23	3.6	38	55.4	23.0	.35
New River at Thurmond, W.Va.	A	16	5.1	24	40.7	18.4	.63
Mill Creek near Hopewell, W.Va.	A	25	4.0	44	60.3	9.0	.21
Williams River at Dyer, W.Va.	A (1997)	13	3.8	23	52.0	30.4	.49
Williams River at Dyer, W.Va.	A (1998)	25	3.5	42	60.1	10.8	.48
Williams River at Dyer, W.Va.	B	28	3.5	44	54.7	12.0	.36
Williams River at Dyer, W.Va.	C	18	2.8	32	52.6	12.2	.42
Sewell Creek at East Rainelle, W.Va.	A	14	5.1	36	25.3	39.0	.36
Miller Creek at Nallen, W.Va.	A	25	3.0	40	80.6	12.6	.39
Peters Creek near Lockwood, W.Va.	A	18	4.5	36	24.9	43.7	.34
Kanawha River below Kanawha Falls, W.Va.	A	11	5.8	25	10.1	85.9	.22
Kellys Creek at Cedar Grove, W.Va.	A	9	5.6	22	26.0	62.6	.63
Laurel Fork near Hacker Valley, W.Va.	A	17	3.4	37	63.4	24.2	.40
Birch River at Boggs, W.Va.	A	24	3.6	49	68.3	19.9	.52
Blue Creek at Sanderson, W.Va.	A	15	5.1	30	31.9	44.0	.30
Sandlick Creek near Arnett, W.Va.	A	15	4.6	32	58.4	14.2	.13
Clear Fork at Whitesville, W.Va.	B (1997)	6	5.1	16	27.3	58.0	.46
Clear Fork at Whitesville, W.Va.	A	9	5.0	21	51.1	27.4	.43
Clear Fork at Whitesville, W.Va.	B (1998)	5	5.4	15	38.5	40.6	.74
Clear Fork at Whitesville, W.Va.	C	9	5.0	24	23.7	56.0	.65
Spruce Laurel Fork at Clothier, W.Va.	A	13	5.2	31	63.1	27.9	.06
Kanawha River above Winfield Dam, W.Va.	A	0	9.7	2	.0	10.0	.00

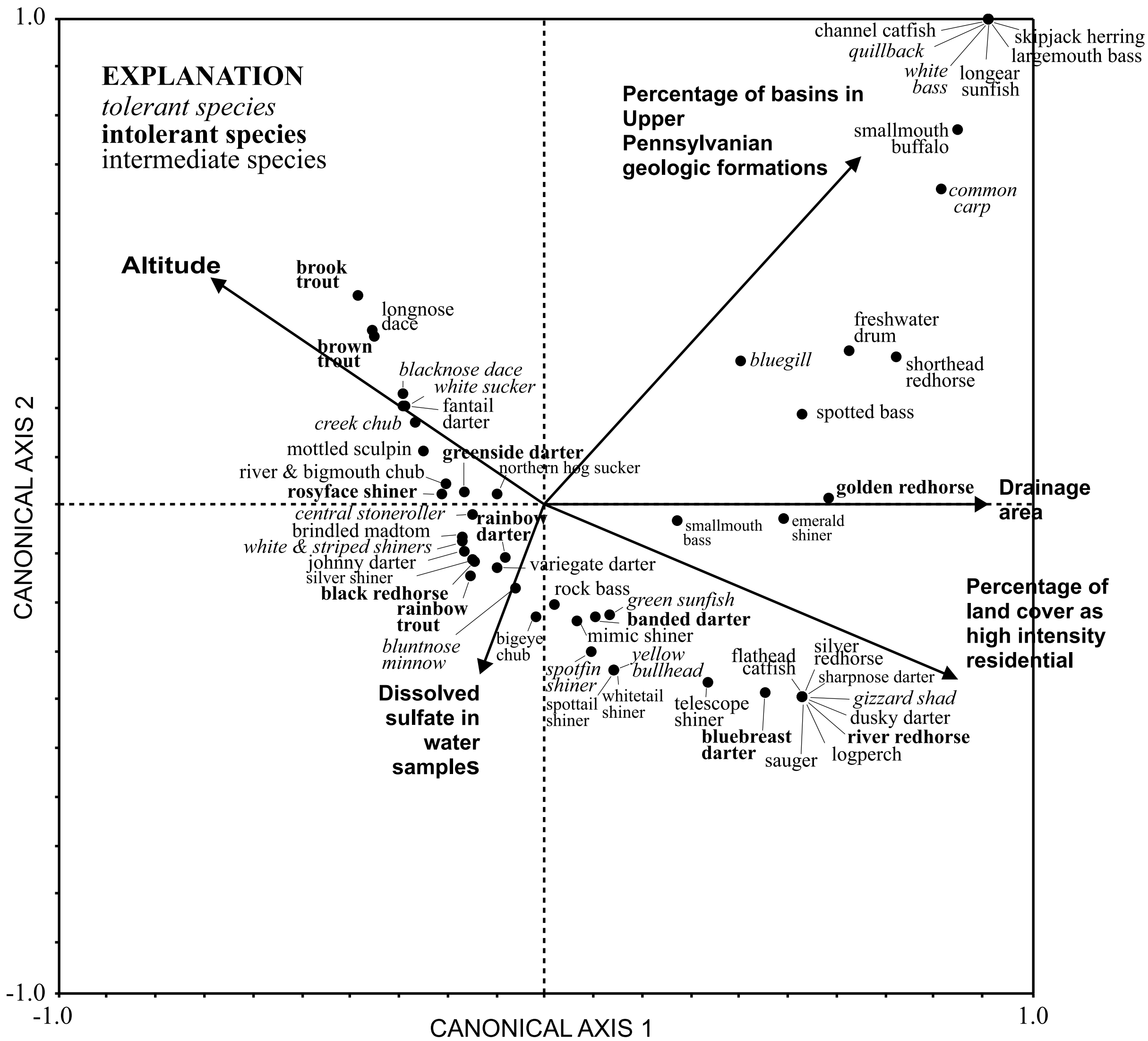


Figure 15. Fish species in the Kanawha River System group along environmental gradients principally by affinity for stream size, rather than according to pollution tolerance. Arrows are environmental gradients shown to affect species composition by canonical correspondence analysis, and species are plotted at their points of greatest abundance relative to environmental gradients. Pollution tolerances are from Halliwell and others (1999).

Sites were divided by stream system and CCA was performed separately on each group. The principal environmental gradient within both groups was dominated by stream size, although to different degrees. Seventy-eight percent of the variation in species from the nine Kanawha River sites was explained by four axes composed of five environmental variables: basin drainage area, altitude, percentage of basin area in Upper Pennsylvanian surficial-geologic formations, percentage of basin area in high-intensity residential and urban land cover, and sulfate concentration in water samples (fig. 15). The first axis was significant ($p < .01$) and most important (eigenvalue = 0.700, and 32.1 percent of species variation) and driven by a combination of drainage area ($r = 0.90$) and high-intensity residential and urban land cover ($r = 0.84$). The second axis was also important (eigenvalue = 0.418, 19.2 percent of species variation) and driven primarily by percentage of basin area in Upper Pennsylvanian surficial geologic formations ($r = 0.70$). The percentage of basin area in Upper Pennsylvanian geologic formations separated Kanawha River above Winfield Dam from all the other sites, and probably was a surrogate for another variable which was not measured, such as volume or

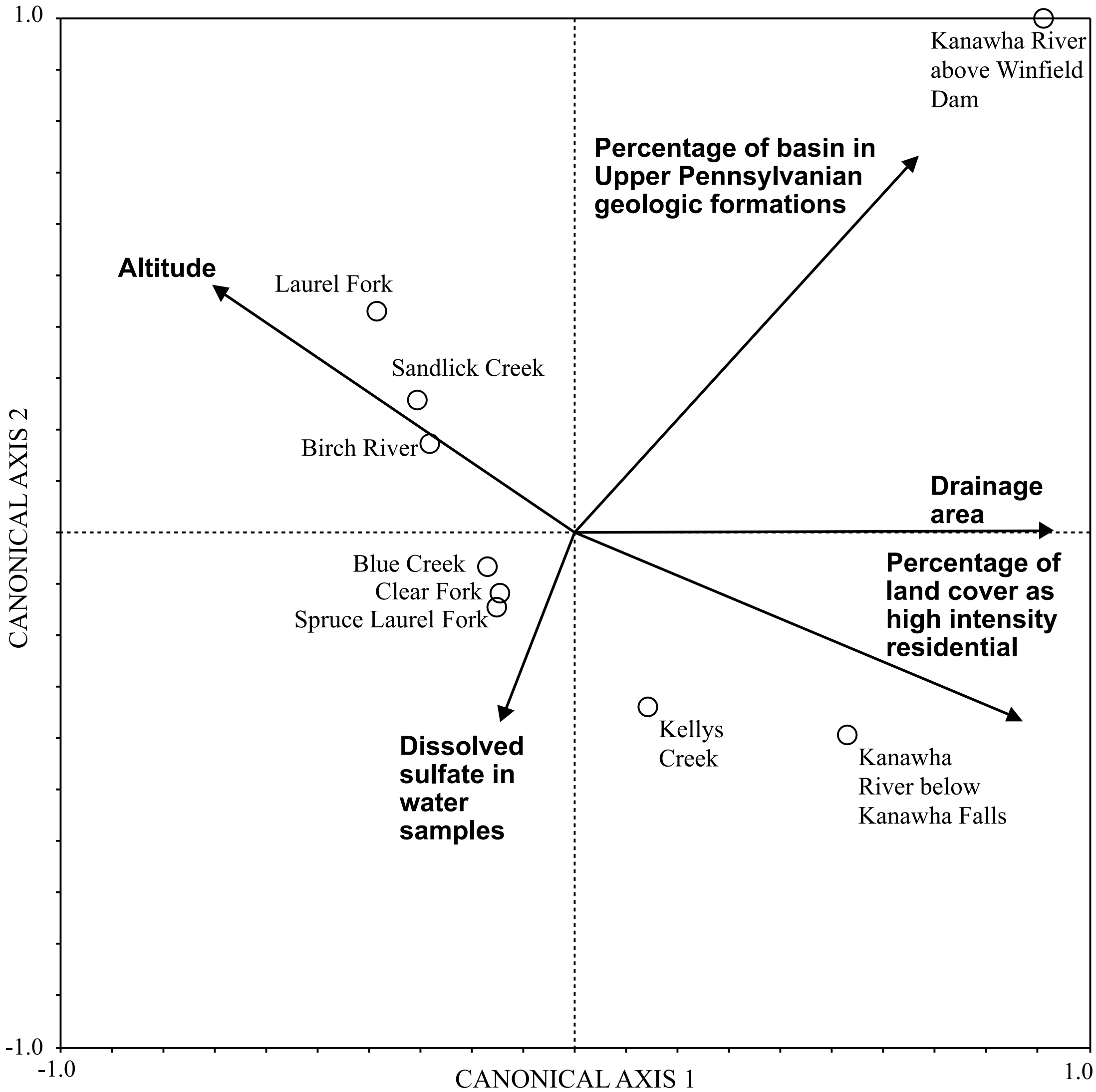


Figure 16. Except for Kanawha River near Winfield, sites from the Kanawha River System are separated along an environmental gradient consisting of drainage area, altitude, and high-intensity residential land cover, according to canonical correspondence analysis.

velocity of water throughout the reach. The third axis also was important (eigenvalue = 0.320, 14.7 percent of species variation), and was driven by sulfate (r = -0.81) and altitude (r = 0.47). The fourth axis was only marginally important (eigenvalue = 0.280); but it explained 12 percent of the species variation, and was driven by a combination of drainage area (r = -0.32), altitude (r = 0.20), and high-intensity residential and urban land cover (r = 0.20).

Kanawha River above Winfield Dam was distinct from all other sites (fig. 16). Kanawha River below Kanawha Falls and Kellys Creek at Cedar Grove group together, and the other six sites grouped together; but all sites except Kanawha River above Winfield Dam were separated along a single, linear gradient. When different combinations of environmental variables and included sites were explored, small sites always grouped together and medium sites always grouped together. Kellys Creek always either grouped with Kanawha River below Kanawha Falls or by itself. No combination of variables led to a grouping of Sandlick Creek near Arnett with the other heavily mined sites, or Blue Creek at Sanderson with the small Elk River subbasin sites.

Stream size drove species distribution along environmental gradients (fig. 15). Several species were collected only from one Kanawha River site, either the site above Winfield Dam or the one below Kanawha Falls, and several other species were collected only at these two sites. Some other species were collected from the main stem or at Kellys Creek at Cedar Grove, but not at any of the smaller streams. The Kellys Creek sampling reach was near the mouth of the stream, and many of the fish collected there probably spent some or most of their lives in the Kanawha River; the presence of typical main stem fish in Kellys Creek probably affected the grouping of this site with Kanawha Falls.

Typical small-stream fish grouped together. These groupings were consistent in exploratory analyses using different sets of environmental variables in addition to basin size. Pollution tolerance had no apparent effect on composition of species groups; typical large-river species gizzard shad (tolerant) and river redhorse (intolerant) grouped together; typical medium-river fish central stonerollers (tolerant), variegate darters, bigeye chubs, and johnny darters (intermediate) grouped with rainbow trout (intolerant); and typical small-stream fish brook trout (intolerant) group with blacknose dace, white suckers, and creek chubs (tolerant).

About half (51.4 percent) of the species variation from the 12 New River sites was explained with a model that included drainage area, percentage of the invertebrate community as midges, total iron concentration in water samples, median streambed-particle size, and percentage of land cover as forest (fig. 17). The first axis was statistically significant ($p = .02$) and the most important (eigenvalue = 0.505, 21.7 percent of species variation). The axis was driven by a combination of drainage area ($r = 0.74$), percentage of land cover as forest ($r = 0.52$), and percentage of invertebrate communities as midges ($r = -0.51$). The second axis was marginally important (eigenvalue = 0.270, 11.2 percent of species variation), and was driven by streambed-particle size ($r = -0.63$), percentage of forest ($r = 0.55$), and drainage area ($r = -0.51$). The other two axes were probably not very meaningful (eigenvalues = 0.229 and 0.194; 9.7 and 8.4 percent of species variation, respectively).

The four variables in the CCA model grouped sites in the New River System into three general groups. The five largest sites in the system grouped together, three medium-sized sites in the Gauley River subbasin grouped together, and the three smallest basins in the system grouped loosely with a medium-sized basin, Second Creek near Second Creek (fig. 17). The Gauley sites were separated from the main-stem sites along the forest vector, and the small sites were separated from the other sites along both the midge percentage and drainage area vectors.

As in the Kanawha River System, stream size strongly affected distribution of species along environmental gradients in the New River System (fig. 18). One noteworthy aspect of species distribution along gradients was that a disproportionate number of introduced species were distributed along the drainage-area vector, in the largest sites. This pattern reflects the status of fish distribution in the New River System, where a large overall number of introduced species is distributed unevenly, and many introduced species are probably moved around barriers within the system by anglers, who more frequently use medium and large streams in the basin.

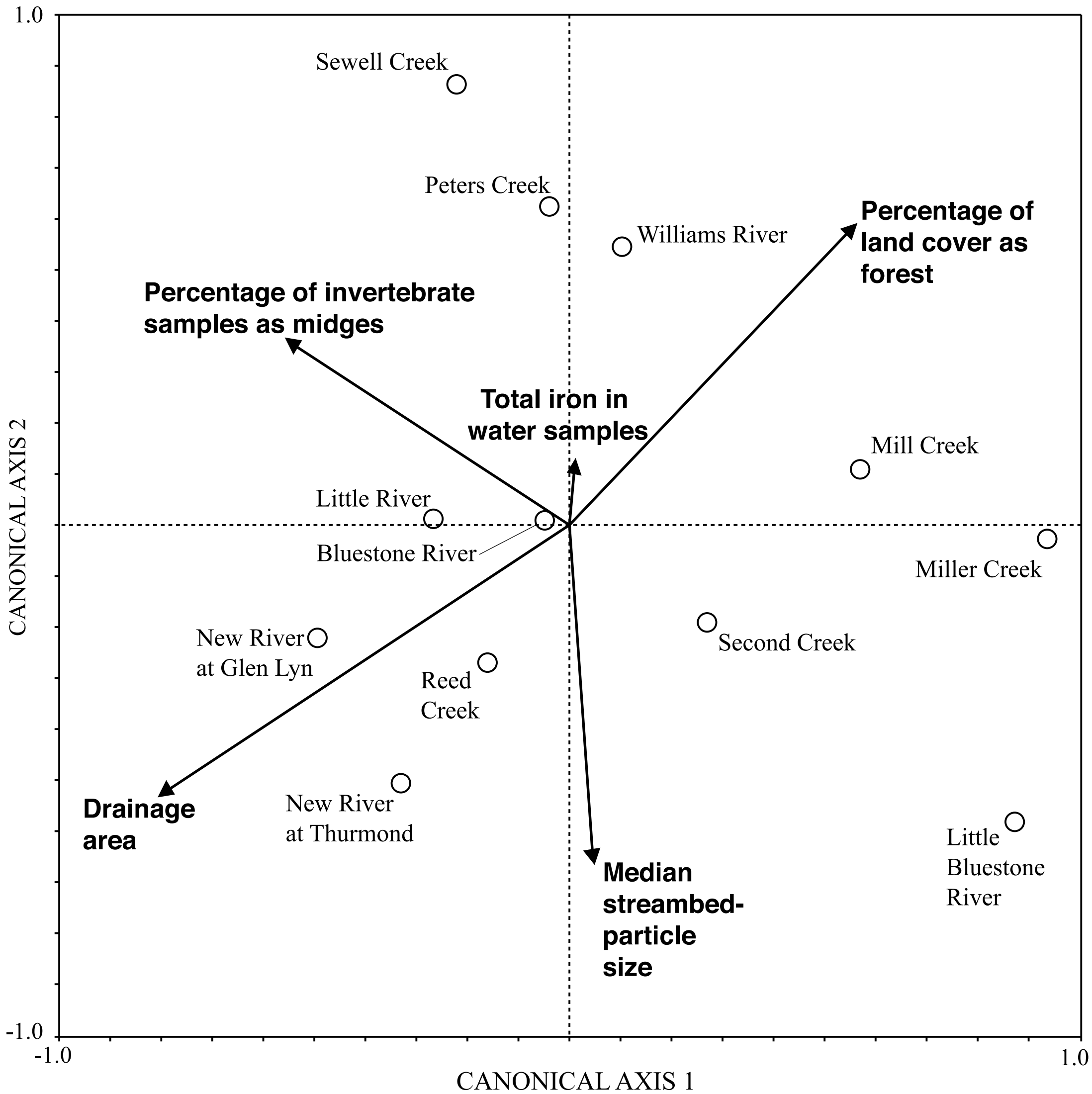


Figure 17. New River System sites are separated along two environmental gradients largely dominated by drainage area and forest. The largest sites grouped near the maximum of the drainage area vector; the three medium-sized sites in the Gauley River subbasin grouped together near the top of the plot; and the smallest sites in the system grouped together loosely.

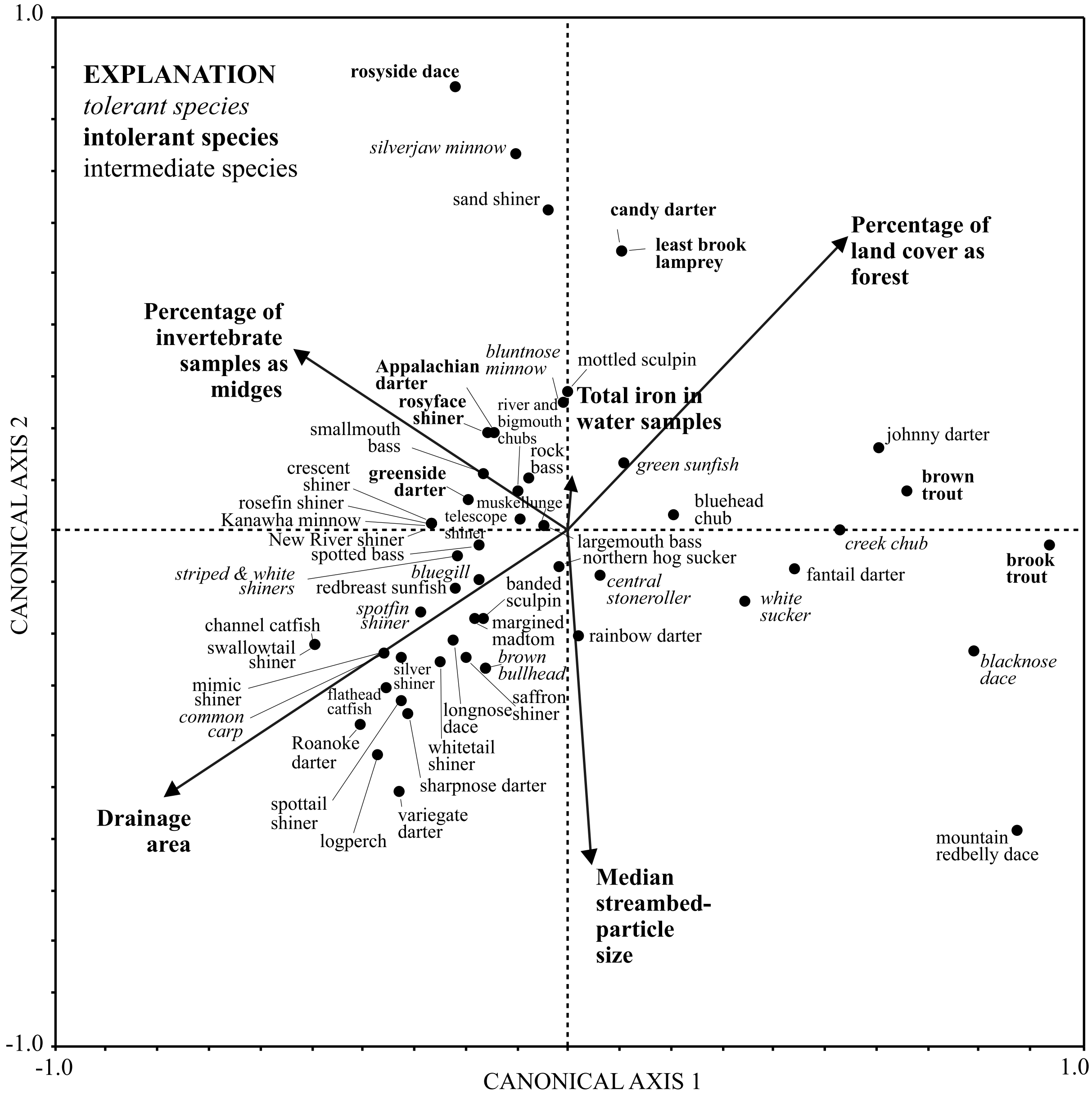


Figure 18. Fish species are distributed along a gradient apparently strongly affected by stream size among New River System sites.

SUMMARY

Stream size and zoogeography masked any water-quality effects of land uses on species composition and relative abundance of fish communities in the 21 sites sampled in the Kanawha River Basin in 1997–98. Drainage areas of sites ranged in size from 8.79 to 11,809 mi^2. Sites from both the New River System and Kanawha River System were sampled. Larger streams generally supported more total species and more species within the minnow, sucker, sunfish, and darter families than smaller streams, even smaller streams of higher quality, although normalizing species counts by site drainage area allowed comparisons among different-sized streams. As described by the River Continuum Concept, tolerance and trophic-status metrics tended to be lower for small streams than for medium and large streams.

Comparison between the New and Kanawha River System sites using metrics based on species counts was problematic, because the New River System naturally lacks native species. Even though enough species have been introduced to the New River System so that the total numbers of species in the two systems is about the same, the distribution of most introduced species and many native species is spotty and inconsistent, and varies throughout the system. Fewer fish species were collected from sites in the New River System than from the Kanawha River System, although size of the New River streams and indicators of environmental quality, including proportional fish metrics, suggested that they would support more species.

Four proportional metrics were used to rank three size classes of sites. Among the four main stem sites, Kanawha River below Kanawha Falls scored best in three of the four proportional metrics, and Kanawha River above Winfield Dam scored worst in three proportional metrics. Five species-composition metrics were used to compare sites within river systems. Among New River streams, Little River at Graysontown, Second Creek near Second Creek, Reed Creek at Grahams Forge, and Williams River at Dyer ranked among the best sites in several species-composition metrics, while Sewell Creek at East Rainelle, Bluestone River near Spanishburg, and Little Bluestone River near Jumping Branch ranked among the worst sites in most species-composition metrics. Among Kanawha River streams, Clear Fork at Whitesville, Kellys Creek at Cedar Grove, and Laurel Fork near Hacker Valley ranked among the best sites in several species composition metrics, and Kanawha River above Winfield Dam, Sandlick Creek near Arnett, and Birch River at Boggs ranked among the worst sites in most species-composition metrics.

Five of 22 candidate metrics were more variable within one or more multi-year, multi-reach sites than among all sites. Two of those were among the most widely used fish metrics, proportion of individual fish with DELT anomalies and number of sucker species. No single fish-community metric was strongly correlated with any single invertebrate-community metric, water-quality indicator, or land use throughout the basin, although several invertebrate metrics were correlated with water-quality indicators and land uses; fish distribution was strongly affected by geographic barriers, and invertebrate distribution was not, and the distribution of disturbance among fish sites was not balanced in the two river systems. The gradient of coal mining sampled in this study, for instance, was representative of the gradient of coal mining that was sampled at invertebrate sites, and several invertebrate metrics were correlated with coal production. Because coal production was heavy at most of the medium Kanawha River System sites (where fish diversity is naturally high) and light at most of the medium New River System sites (where fish diversity is naturally low), the relation between coal mining, related chemical and physical stream characteristics, and fish metrics was ambiguous.

According to two-way indicator species analysis (TWINSPAN), the first separation among sites was between the two largest sites (Kanawha River below Kanawha Falls and Kanawha River above Winfield Dam) and the rest of the sites. When species complexes were combined, the second-level splits among sites were dominated by stream size. The smallest sites in the basin grouped together, and medium-sized sites grouped with two New River main stem sites. The third-level split among the group of larger sites was by either size or physiography; small-to-medium sized sites from the Appalachian Plateaus grouped together, and larger sites draining the Blue Ridge and Valley and Ridge grouped together.

Ordination methods were not useful in distinguishing the relation between fish community composition and environmental gradients throughout the basin, because these methods assume species can move to the locations where their physiological optimum conditions are met. Fish distribution in the Kanawha

River Basin is strongly affected by Kanawha Falls and the numerous other barriers that prevent fish species from moving freely through the basin. When CCA was performed separately on each river system, both were dominated by stream size, although to different degrees. Kanawha River above Winfield Dam was separated from all other sites. Kanawha River below Kanawha Falls and Kellys Creek at Cedar Grove grouped together, and the other six sites grouped together. No combination of variables led to a grouping of heavily mined but small Sandlick Creek near Arnett with the heavily mined, medium-sized sites, or heavily mined, medium-sized Blue Creek at Sanderson with the small sites in the Elk River subbasin. Stream size also drives species distribution along gradients. Several species were collected only from one or both of the Kanawha River main stem sites. Typical small-stream fish group together.

The four variables in the New River System CCA model grouped sites into three general groups. The five largest sites in the system grouped together, three medium-sized sites in the Gauley River subbasin grouped together, and the three smallest basins in the system grouped loosely with a medium-sized basin, Second Creek near Second Creek. Stream size strongly affected distribution of species along environmental gradients in the New River System, as in the Kanawha River System.

Several species of fish, including telescope shiners and margined madtoms, have expanded their ranges in the New River System, largely because unused bait fish were released by anglers. These range expansions took place during a period when changes in regulations and land use have generally improved water quality in many parts of the New River System. No similar range expansions have been observed in Kanawha River System streams, which have undergone similar changes in the physical and regulatory environments. Percentages of non-native fish were greatest at some sites where invertebrate metrics and other indicators of environmental quality classified among the best sites in the study network.

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