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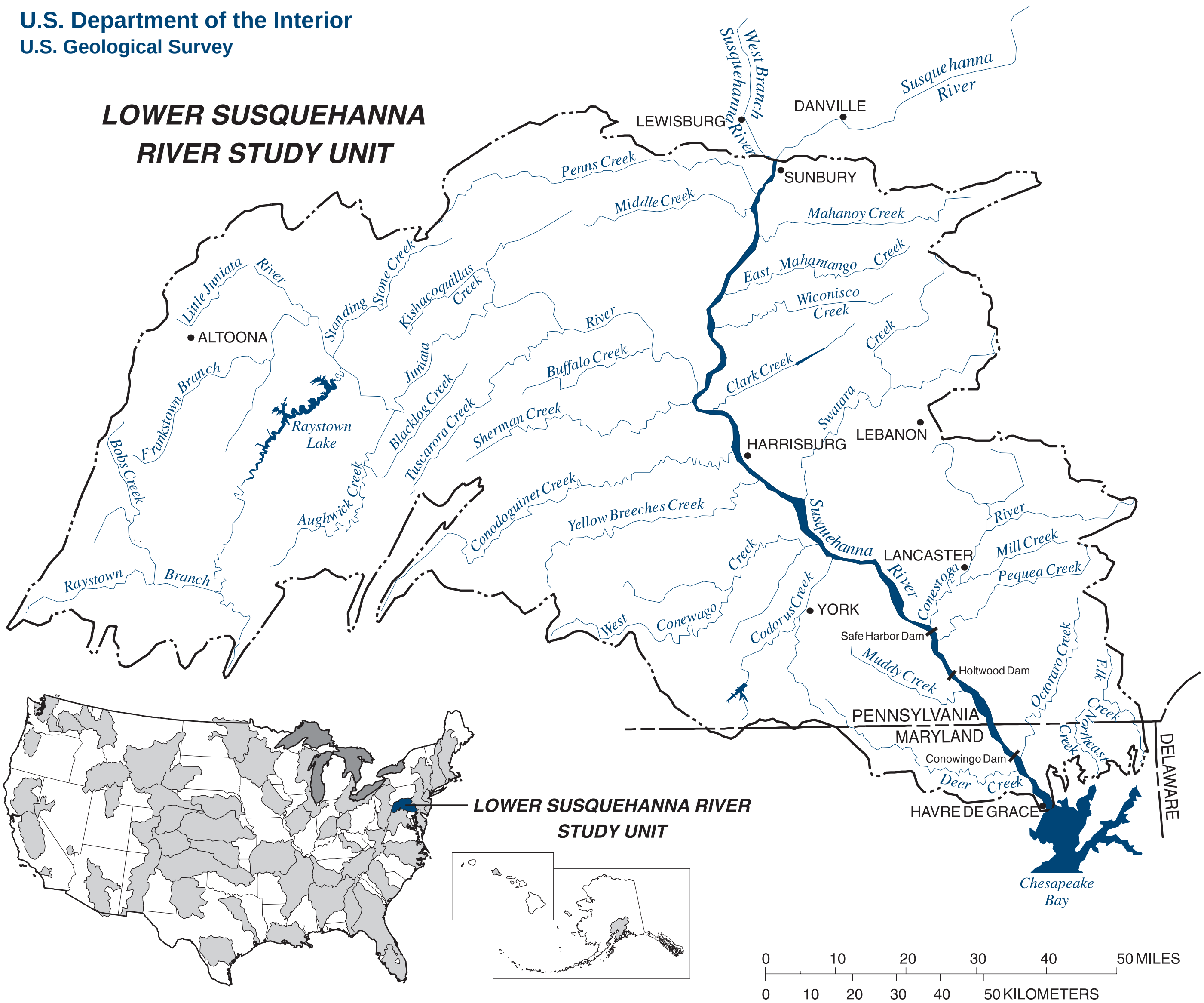
Fish Communities and Their Relation to Physical and Chemical Characteristics of Streams from Selected Environmental Settings in the Lower Susquehanna River Basin, 1993-95

Water-Resources Investigations Report 98-4004

U.S. Department of the Interior

U.S. Geological Survey



NATIONAL WATER-QUALITY ASSESSMENT PROGRAM STUDY UNITS

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

FISH COMMUNITIES AND THEIR RELATION TO PHYSICAL AND CHEMICAL CHARACTERISTICS OF STREAMS FROM SELECTED ENVIRONMENTAL SETTINGS IN THE LOWER SUSQUEHANNA RIVER BASIN, 1993-95

by Michael D. Bilger and Robin A. Brightbill

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U.S. Department of the Interior
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NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Lemoyne, Pennsylvania
1998

U.S. DEPARTMENT OF THE INTERIOR
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Information regarding the National Water-Quality Assessment (NAWQA) Program is available on the Internet via the World Wide Web. You may connect to the NAWQA Home Page using the Universal Resource Locator (URL) at:

http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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	Multiply	by	To obtain
Length			
	millimeter (mm)	0.03937	inch
	centimeter (cm)	.3937	inch
	meter (m)	3.281	foot
	kilometer (km)	.6214	mile
Area			
	square kilometer (km^2)	.3861	square mile
Volume			
	cubic meter per second (cm^3/s)	35.31	cubic foot per second

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8(°C) + 32$$

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L), micrograms per liter (µg/L), or milligrams per kilogram (mg/kg). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute 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. Milligrams per kilogram is a unit expressing the concentration of chemical constituents as weight (milligrams) of constituent per unit weight of the solid matrix (kilograms) in which the constituent is found. Milligrams per kilogram is used to express constituent concentrations in streambed sediment.

Specific electrical conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

Fish Communities and Their Relation to Physical and Chemical Characteristics of Streams from Selected Environmental Settings in the Lower Susquehanna River Basin, 1993-95

by Michael D. Bilger and Robin A. Brightbill

ABSTRACT

Studies of fish-community composition were conducted annually in selected reaches (from 100 to 303 meters in length) on seven streams from June 1993 to June 1995 within the Lower Susquehanna River Basin. In 1994, additional reaches were selected on three of the streams, resulting in a total of 28 samples. The study reaches were selected on the basis of type of bedrock and land use/land cover; the major emphasis was on agricultural land use or areas in transition from agricultural to commercial, industrial, and residential land uses. At each reach, environmental characteristics consisting of instream and riparian habitat conditions, hydrology, and water quality were determined. The relation of fish communities at these reaches to physical and chemical characteristics of streams was analyzed to determine if the fish communities differed temporally or spatially. Data were analyzed by parametric and multivariate techniques.

During the course of the study, a total of 33,143 fish were collected, consisting of 39 species representing 8 families. Cyprinidae (minnows) were dominant with 17 species, followed by Centrarchidae (sunfishes) with 7 species and Percidae (perches and darters) with 4 species. Three species—blacknose dace (*Rhinichthys atratulus*), white sucker (*Catostomus commersoni*), and the sculpins (*Cottus* spp)—accounted for 49 percent of the total fish collected.

The environmental variables most closely related to the fish communities present at the reaches were mean channel width, mean water temperature, mean canopy angle, and suspended-sediment concentrations. These variables accounted for about 79 percent of the variation in the environmental-species relation. Channel width and mean water temperature are correlated with stream size variables. The stream size gradient is the most influential variable to the fish communities studied in the Lower Susquehanna River Basin.

INTRODUCTION

The NAWQA Program

The U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program is a long-term effort to describe the status of, and trends in, the quality of the Nation's surface- and ground-water resources and to provide an understanding of the natural and human factors that affect the quality of these resources (Hirsch and others, 1988; Leahy and others, 1990). The program will address water quality at a wide range of spatial scales, from local to national, and will focus on persistent water-quality conditions that affect large areas of the Nation or occur commonly within small areas. NAWQA is an integrated assessment program incorporating physical, chemical, and biological components (Gurtz, 1994).

The NAWQA design consists of studying 59 individual hydrologic systems throughout the United States that represent about 60 to 70 percent of the Nation's water use. Assessments of the first 20 study units began in 1991 with 4-5 years of intensive assessment activity followed by 5 years of low-intensity assessment, and then repeating the cycle (Gilliom and others, 1995). Assessments began in 16 additional study units in 1994 and in another 12 in 1997 to continue the program on a rotational rather than a continuous basis.

Purpose and Scope

This report relates the fish-community composition to physical and chemical gradients, including habitat, hydrology, and water quality, in the Lower Susquehanna River Basin. These analyses contribute to the multiple lines of evidence approach that the NAWQA Program utilizes to assess the quality of aquatic resources and represents one component of the overall Lower Susquehanna River Basin ecological program. The Lower Susquehanna River Basin, rather than the entire Susquehanna River Basin, was selected so that resources could be focused where land-use activities associated with intensive agriculture and heavily populated areas are most likely to affect water quality.

Description of Study Area

The Lower Susquehanna River Basin begins at the confluence of the West Branch and mainstem of the river at Sunbury, Pa., and extends downstream to the Chesapeake Bay at Havre de Grace, Md. The basin consists of approximately 23,828 km^2 (9,200 square miles) of the 69,930 km^2 (27,000 square miles) that compose the entire Susquehanna River watershed (fig. 1). A detailed description of the environmental settings that are present in the study unit are given in Risser and Siwiec (1996).

Physiography and Land Use

The Lower Susquehanna River Basin study unit contains parts of five distinct physiographic provinces: the Appalachian Plateaus, Ridge and Valley, Blue Ridge, New England, and Piedmont (Berg and others, 1989); the majority of the basin area is represented by the Ridge and Valley (68 percent) and the Piedmont (29 percent) Physiographic Provinces (Risser and Siwiec, 1996). These physiographic provinces offer distinctive characteristics derived from their particular geologic framework, which in turn give rise to distinctive landforms that result in particular types of vegetation, soils, water, and climate (Hunt, 1967, p. 3). Water quality is greatly affected by these landforms because they control the distribution of precipitation and the physical pathways that surface runoff and ground water follow to the Susquehanna River. Basin relief, hillslope morphology, and stream-drainage pattern dictate the residence time of runoff with soil,

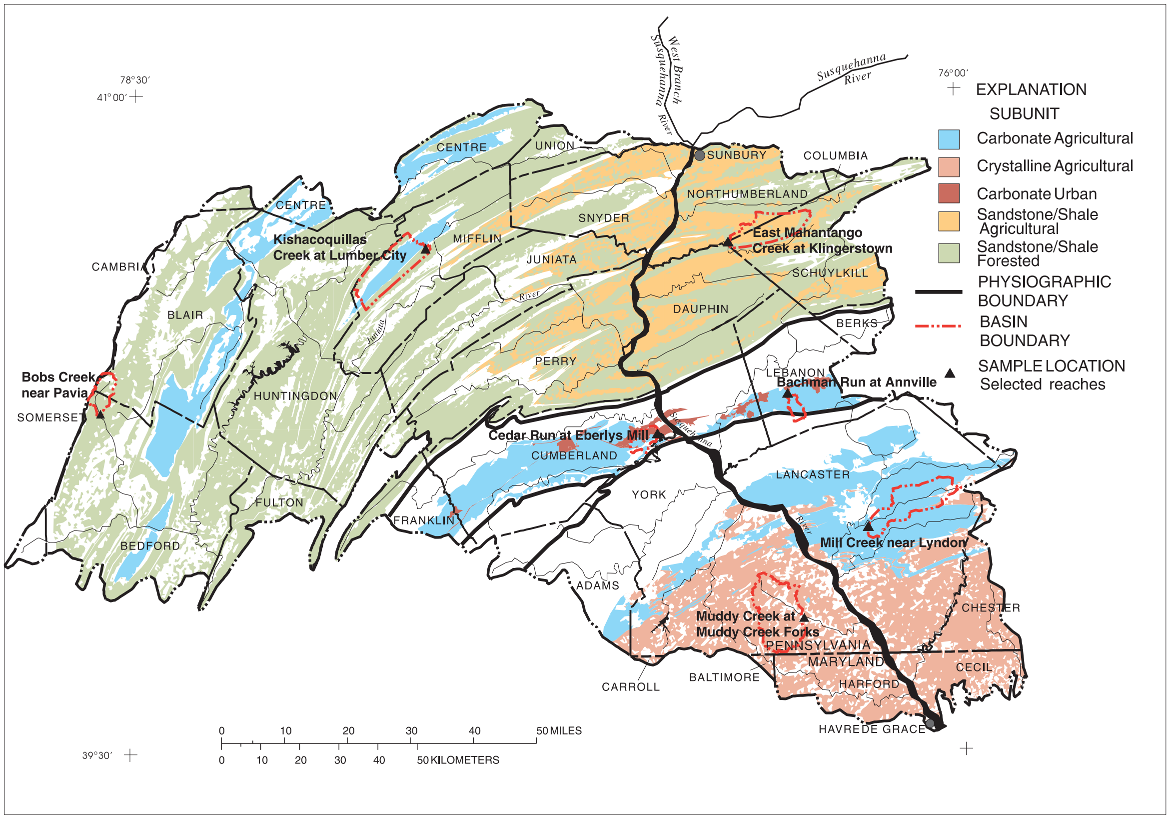

Figure 1. The Lower Susquehanna River Basin, counties, major environmental subunits, and location of the principal reaches surveyed for fish communities from 1993 to 1995.

rocks, and vegetative cover—all factors that affect the sediment and natural chemical composition of surface and ground waters in the basin.

Ecoregions are defined as areas of relative homogeneity in ecological systems and their components. Factors associated with spatial differences in the quality and quantity of ecosystem components, including soils, vegetation, climate, geology, and physiography, are relatively homogeneous within an ecoregion. Ecoregions may be separated by different patterns of human stresses on the environment and by different patterns in the existing and attainable quality of environmental resources, and the concept of ecoregions has proven to be an effective aid for inventorying and assessing national and regional environmental resources, for setting resource-management goals, and for developing biological criteria and water-quality standards (Woods and others, 1996).

A Roman numeral classification scheme has been adopted to eliminate confusion in explaining ecoregions; Level I, the coarsest, divides North America into 15 regions; Level II divides the continent into 52 classes; and Level III divides the continent into 98 ecoregions. Level IV ecological regions are further subdivisions of Level III units compiled from 1:250,000-scale bases. The numbers of these ecological units continue to change as they undergo development at all levels (Woods and others, 1996).

Three level III ecoregions are represented within the Lower Susquehanna River Basin. From east to west, they are the Northern Piedmont, the Blue Ridge Mountains, and the Central Appalachian Ridges and Valleys. The Ridge and Valley Region is further divided into 10 level IV ecoregions; 5 are within the basin—the Northern Limestone/Dolomite Valleys, Northern Shale Valleys, Northern Sandstone Ridges, the Northern Dissected Ridges, and Anthracite. The Northern Piedmont Region is further divided into four level IV ecoregions, all of which are within the study basin boundaries—Triassic Lowlands, Diabase and Conglomerate Uplands, Piedmont Uplands, and Piedmont Limestone/Dolomite Lowlands. The Blue Ridge Region is divided into five level IV ecoregions, two of which are within the study basin—Northern Igneous Ridges and Northern Sedimentary and Metasedimentary Ridges.

Land use within the Lower Susquehanna River Basin is evenly divided between agriculture (47 percent) and forested (47 percent). Urban and built-up areas cover about 4 percent of the basin; the remaining 2 percent consists of waterbodies and barren lands. Overall, patterns of land use are reflective of the differences in the physical characteristics of the basin.

Previous Studies of Fish Communities

Numerous studies of fish communities have been conducted within the Lower Susquehanna River Basin; most studies, however, were not made near the reaches selected for this study. The principal investigators for many of these studies included biologists from the Pennsylvania Fish and Boat Commission (PFBC), the Pennsylvania Department of Environmental Protection (PaDEP), the Susquehanna River Basin Commission (SRBC), the hydroelectric power industry, and various private environmental consultants and academic institutions.

Two comprehensive environmental studies have been conducted within the Lower Susquehanna River Basin. In 1976, the PaDEP conducted fish-community studies as part of a 150-station network in the Lower Susquehanna River Basin (Brezina and others, 1980). Algae, zooplankton, aquatic macrophytes, invertebrates, and fish collections were made. In 1985, the SRBC conducted aquatic-community studies at approximately 160 sites in the lower basin noting presence or absence of fish species (McMorran, 1986a; 1986b). The PaDEP and SRBC sites were frequently co-located. In addition, Greeley (1936), Bielo (1963), Denoncourt (1975), Denoncourt and Cooper (1975), Zuck and Denoncourt (1979), Cooper (1983) and the PFBC (mostly unpublished reports) conducted studies of the fish community within the Lower Susquehanna River Basin.

ACKNOWLEDGMENTS

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METHODS

Reach Selection

Prior to selection of the principal reaches, the study unit was subdivided into 12 relatively homogeneous subunits. The subunits were based on physiography, bedrock type, and in some cases land use and land cover.

A geographic information system (GIS) was used to define the subunits. Each of these subunits were considered for reach selection. The NAWQA program, the study-unit liaison committee, and other local agencies were primarily concerned with water-quality influences associated with agricultural land use. The most intense agricultural areas are underlain by carbonate bedrock. Therefore, these two factors were given major consideration in the choice of principal reaches. Another consideration in reach selection was for those areas in transition from agricultural to commercial, industrial, and residential uses and the resulting effects on water quality (Siwiec and others, 1997).

On the basis of these water-quality issues, basins in seven subunits were chosen. Within each basin, reaches were selected (table 1) so that the most apparent influence on the water quality at that point was the bedrock type and the land use that the basin was selected to represent. The number of samples for water quality was calculated using the monthly minimum, maximum, and mean for each month the data were collected between 1993 and 1995 (Durlin and Schaffstall, 1994; 1996; 1997) and instantaneous field measurements.

Four limestone streams were chosen for study (table 1). Limestone streams are located in valley areas and flow through a bedrock of limestone or through an area interspersed with limestone deposits (Shaffer, 1991). Stream characteristics include alkalinities of 75-150 ppm (parts per million) or greater, a stable pH of 7.5-8.0 pH units year around, low gradient, high abundances of aquatic plants and invertebrate life, and nearly constant ambient water temperatures throughout the year.

Three freestone streams also were chosen (table 1). Sandstone, shale and other noncarbonate rocks are associated with freestone streams. These streams tend to be fed from runoff and by small feeder-type streams and gain water a little at a time. These streams also tend to flow off ridges and are fed from a single watershed, unlike limestone streams, which can collect water from multiple watersheds connected by underground flow over great distances.

The PaDEP classifies water uses according to specific water-quality criteria. Among these water uses are designations of types of fisheries (cold water, warm water, trout stocking, high-quality, exceptional-value) and a series of temperature and dissolved oxygen (DO) criteria that reflect the more sensitive uses (Pennsylvania Department of Environmental Resources, 1989). The streams designated for trout stocking are listed on table 1.

Table 1. *Locations and selected water-quality characteristics of streams studied for assessments of fish communities in the Lower Susquehanna River Basin, Pennsylvania and Maryland*

[°C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; Min, minimum; Max, maximum; n, number of data points]

Station name	Latitude/ longitude	Stream type	Trout stock	Water temperature (°C)				pH				Dissolved oxygen (mg/L)				Specific conductance (µS/cm at 25°C)			
				Min[3]	Max[3]	Mean[3]	n	Min[3]	Max[3]	Mean[3]	n	Min[3]	Max[3]	Mean[3]	n	Min[3]	Max[3]	Mean[3]	n
Bobs Creek near Pavia, Pa.[1]	40°16′21″/ 78°35′55″	freestone	no	0	26	16	42	6.6	7.7	7.1	31	5.9	14	9.4	30	51	94	68	497
Cedar Run at Eberlys Mill, Pa.	40°13′30″/ 76°54′24″	limestone	no	5.8	23	15	98	6.8	8.4	8.0	94	5.3	14	10	78	119	970	645	740
Unnamed Tributary to Unnamed Northern Tributary to Cedar Run at Eberlys Mill, Pa.[2]	40°13′34″/ 76°55′10″	limestone	no	14	15	15	5	7.2	7.2	7.2	3	7.2	7.9	7.7	3	739	780	763	3
Unnamed Northern Tributary to Cedar Run at Eberlys Mill, Pa.[2]	40°13′27″/ 76°55′04″	limestone	no	15	16	15	6	7.2	7.7	7.5	4	8.2	9.0	8.7	3	704	800	765	3
Cedar Run at Shiremanstown, Pa.[2]	40°13′03″/ 76°56′20″	limestone	no	14	16	14	6	7.1	7.6	7.3	4	8.2	8.7	8.4	3	634	800	731	3
Mill Creek at Eshelman Mill Road near Lyndon, Pa.	40°00′36″/ 76°16′39″	limestone	no	1	26	17	110	7.1	8.6	7.9	154	5.9	14	8.5	59	213	861	662	500
Bachman Run at Annville, Pa.	40°18′59″/ 76°30′58″	limestone	yes	6.4	21	13	65	6.5	8.4	8.0	59	5.1	14	11	47	359	810	592	248
Kishacoquillas Creek at Lumber City, Pa.	40°39′42″/ 77°36′01″	limestone	yes	1.3	24	15	40	8.0	9.0	8.4	34	7.0	15	11	28	179	757	437	420
East Mahantango Creek at Klingerstown, Pa.[1]	40°39′48″/ 76°41′30″	freestone	yes	0	27	16	80	6.5	8.7	7.5	70	7.1	14	9.6	67	50	206	145	532
Muddy Creek at Muddy Creek Forks, Pa.	39°48′27″/ 76°28′34″	freestone	yes	0	26	16	35	6.2	8.5	7.6	30	8.1	14	9.9	27	60	260	127	279

[1] These are three-reach stations.
[2] These are additional reaches upstream of Cedar Run at Eberlys Mill, Pa.
[3] Three-year period (1993-95).

The principal reaches selected for fish-community studies were within two level III ecoregions—the Ridge and Valley and the Northern Piedmont. Within the Ridge and Valley ecoregion, three level IV ecoregions were represented by five sampling reaches (table 2). Both the Cedar Run and Bachman Run locations are within the Northern Limestone/Dolomite Valleys, which are characterized by broad, level to undulating fertile valleys that are farmed extensively. Drainage density is low, and streams tend toward gentle gradients with plentiful year-round flow and distinctive fish assemblages. Local relief typically ranges from 15 to 152 m. Vegetation is classified as mostly Appalachian oak forest in the north and oak/hickory/pine forest in the south. The East Mahantango Creek reach is on the border between the Northern Shale Valleys and the Northern Sandstone Ridges. The Northern Shale Valleys ecoregion is characterized by rolling valleys and low hills. Local relief varies from 15 to 152 m. Surface streams tend to be larger and drainage density higher than limestone areas. Streams also tend to exhibit more turbidity with impaired stream habitat. Vegetation resembles that of the Northern Limestone Valleys. The Northern Sandstone Ridges, in addition to the East Mahantango Creek, includes the reaches at Bobs Creek and Kishacoquillas Creek and are characterized by high, steep, forested ridges with narrow crests. Local relief ranges from 305 to 1,311 m with high-gradient, poorly buffered streams flowing into the valleys. The vegetation is similar to that in other ecoregions; however, the area remains heavily forested.

Within the level III Northern Piedmont ecoregion, two level IV ecoregions were represented by two sampling reaches. The Muddy Creek reach lies in the Piedmont Uplands, which are underlain by metamorphic rock and characterized by rolling hills and low ridges. This is an area of irregular plains and narrow valleys where the local relief can be as much as 180 m. Remnants of the Appalachian oak forests persist in the deep gorges. Specialized habitats exist here, such as the serpentine barrens, that support many vegetative species rare to Pennsylvania. The Piedmont Limestone/Dolomite Lowlands, which includes the Mill Creek reach, is underlain by limestone and dolomite and presents very fertile farming conditions. Many sinkholes, caverns, and disappearing streams occur in this region. Local relief typically is only 9 to 38 m. Appalachian oak forests originally grew here but have been mostly replaced by some of the most productive agricultural uses in the state.

Five of the reaches chosen were in dominant agricultural land-use areas. Three of the reaches are in the Ridge and Valley Physiographic Province (two in the Appalachian Mountain Section, one in the Great Valley Section). The two remaining reaches were within the Piedmont Physiographic Province. Of the five agricultural reaches, three lie in carbonate settings, one is underlain by siliciclastic rock, and the remaining one is underlain by crystalline rock (table 2).

Two principal reaches are located in areas considered nonagricultural. These were an urban reach, Cedar Run, in the carbonate setting of the Great Valley Section and a forested reference reach, Bobs Creek, underlain by siliciclastic rock in the Appalachian Mountain Section of the Ridge and Valley Province.

Habitat Quantification

Following the NAWQA habitat protocols (Meador and others, 1993b), a set of habitat parameters was quantified at each of the principal reaches in 1993 and at additional multiple reaches and at reaches upstream of Cedar Run at Eberlys Mill in 1994. NAWQA protocols are based on four spatial scales—basin, segment, stream reach, and microhabitat. Biological investigations began within the study unit at the segment level by

Table 2. *Principal study reaches and the physiographic province and ecoregion associated with each reach*

Site name	Physiographic province	Level III Ecoregions	Level IV Ecoregions	Environmental subunits	Land use designation at study sites
Bobs Creek near Pavia	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Sandstone Ridges	Appalachian Mountain Sandstone and Shale Forested	Forested
Cedar Run at Eberlys Mill	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Limestone/ Dolomite Valleys	Great Valley Carbonate Urban	Urban
Mill Creek near Lyndon	Piedmont	Northern Piedmont	Piedmont Limestone/ Dolomite Lowlands	Piedmont Carbonate Agricultural	Agricultural
Bachman Run at Annville	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Limestone/ Dolomite Valleys	Great Valley Carbonate Agricultural	Agricultural
Kishacoquillas Creek at Lumber City	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Sandstone Ridges	Appalachian Mountain Carbonate Agricultural	Agricultural
East Mahantango Creek at Klingerstown	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Shale Valleys/ Northern Sandstone Ridges	Appalachian Mountain Sandstone and Shale Agricultural	Agricultural
Muddy Creek at Muddy Creek Forks	Piedmont	Northern Piedmont	Piedmont Uplands	Piedmont Crystalline Agricultural	Agricultural

examining a 7.5-minute topographic quadrangle map to determine the characteristics of slope, stream order, sinuosity, segment length, elevation, side slope gradient, segment gradient, stream order, drainage area, drainage density, drainage shape, and basin relief.

At the stream-reach scale, channel features included geomorphic units that were used to define the sampling reach, stream width, instream cover, macrophyte cover, and substrate (Meador and others 1993b). The percent overhanging vegetation and canopy angle of riparian vegetation also were recorded. The microhabitat scale included characteristics such as depth, velocity, and particle size of the bed material.

Habitat quantification (Meador and others, 1993b) consisted of recording 35 features, some of which were direct measurements and others subjective observations. The features used in the analysis of fish communities were reach length, channel width, bank width, flood-plain width, depth, velocity, streambed substrate, embeddedness, vegetation canopy angle, bank stability, bank erosion, bank substrate, and percentages of habitat features including woody snags, overhanging vegetation, undercut banks, boulders, emergent macrophytes, submerged macrophytes, and rubbish. Pebble counts (Wolman, 1954) were conducted at three transects—top, middle, and bottom—within each reach to determine particle-size distribution in the bed material. Two combined variables were calculated from the raw data. A Bank Stability Index (BSI) (Simon and Downs, 1995) was calculated using bank angle, bank cover, bank height, and bank material. A width to depth ratio also was calculated.

Water-Chemistry Measurements and Data Analysis

Field measurements of water temperature, DO, pH, and specific conductance were recorded at the principal reaches each time ecological samples were collected. Similar data also were recorded when water samples for chemical analysis were collected. Nitrate, ammonia, dissolved organic carbon (DOC), total phosphorus, dissolved phosphorus, and suspended sediment were included in the data for the study of fish communities. Methods of data collection are given in Siwiec and others (1997). Yearly mean concentrations of these water-chemistry constituents were calculated for each of the years from 1993 to 1995.

Periphyton, chlorophyll *a*, chlorophyll *b*, and ash free dry mass (AFDM) also were analyzed. These samples were collected according to the NAWQA protocols for algal studies (Porter and others, 1993) and analyzed at the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo.

Water-quality characteristics at the seven Lower Susquehanna River Basin principal reaches were monitored from 1993 to 1995. No historical water-quality records were collected by the USGS at these sites. Mean 3-year values of water temperature, pH, DO, and specific conductance are shown in table 1. Means were used in the analysis because there was no opportunity to measure the extreme values. However, the means may not always be the best values to show stress to the fish communities at these streams. The mean water temperature in limestone streams ranged from 13 to 17°C and in freestone streams was 16°C. The mean pH ranges show a similar overlap. In limestone streams pH ranged from 7.2 to 8.4 and in freestone streams from 7.1 to 7.6. Mean DO ranged from 7.7 to 11 mg/L in limestone streams and from 9.4 to 9.9 mg/L in freestone streams. Mean specific conductance was greater in the limestone streams where it ranged from 592 to 731 µS/cm; specific conductance in freestone streams ranged from 68 to 145 µS/cm. DOC also was measured and averaged 4.4 mg/L in limestone streams and 9.4 mg/L in freestone streams.

Average yearly concentrations of suspended sediment were generally higher in limestone than freestone streams. Suspended sediments in limestone streams ranged from 20 to 118 mg/L and in freestone streams from 4 to 45 mg/L. Limestone streams had more average year to year variability in suspended-sediment concentrations that ranged from 41 to 80 mg/L; freestone streams had average yearly differences that ranged from 0 to 29 mg/L.

Nutrients measured at the principal reaches were total phosphorus, dissolved phosphorus, nitrate, and ammonia. These were calculated as yearly averages for each reach. The average concentration of total phosphorus in limestone streams was 0.22 mg/L as P and in freestone streams was 0.11 mg/L as P. Concentrations of dissolved phosphorus exhibited little difference between the two stream types; average concentration in limestone streams was 0.07 mg/L as P and in freestone streams was 0.1 mg/L as P. Nitrates averaged 7.9 mg/L as N in limestone streams and 4.2 mg/L as N in freestone streams. The average ammonia concentration in limestone streams was 0.4 mg/L as N and in freestone streams was 0.3 mg/L as N.

Hydrologic Measurements and Data Analysis

Data on hydrologic variables were measured on USGS 7.5-minute topographic quadrangle maps and through field collections. Topographic maps were used to determine channel sinuosity, drainage texture, and stream length as described in the NAWQA protocols for stream habitat characterization (Meador and others, 1993b). Thalweg depth was measured by use of a wading rod. Velocity and discharge were measured instream by use of either a pygmy or a Price AA current meter depending on the depth of the water (Meador and others, 1993b). Annual precipitation information was obtained from Durlin and Schaffstall (1994).

The hydrologic data were examined during the 3-year intensive collection period and over the long term to check on the variability of streamflows and any deviations from the average. Fish-community sampling and the resultant analysis of collected data can be affected by antecedent hydrologic events and by hydrologic conditions during the period of data collection. Streamflow data collected at these reaches over 2-3 years is too short a period to develop any meaningful streamflow statistics for a comparative analysis to previous years. For this reason, surrogate streamflow-monitoring stations with longer periods of record were chosen to represent each of the principal reaches where fish-community data were collected (table 3). The surrogate stations were selected because they were in the same or an adjacent basin and had similar basin and streamflow characteristics.

Two types of hydrologic information are included in table 3. The range and mean of daily mean streamflows for each of the 5 years preceding data collection (1988-92) are provided to document any extreme hydrologic events that may have significantly altered the stream habitat and, subsequently, the fish-community composition immediately prior to the data collection. The maximum daily mean streamflow for five of the seven stations during the 1988-92 period was in the 1989 water year—4 years prior to the data-collection period. The remaining two maximums were in 1988 and 1991. Daily streamflows were used to generate duration tables for each of the principal reaches. Annual mean streamflows computed at the stations for each of the 5 years ranged within the 25th to 75th percentile of all daily mean streamflows measured and thus did not exceed those that would normally be expected. The conclusion of this analysis is that no extreme hydrologic events occurred prior to the data-collection period that would have significantly altered the stream habitat and the fish-community composition.

Table 3. *Streamflow statistics for streamflow-measurement stations with long-term record comparable to streams studied in the Lower Susquehanna River Basin, Pennsylvania and Maryland*

[ft^3/s, cubic feet per second; Max, maximum; Min, minimum]

Streamflow-measurement station with long-term record (surrogate station) number and name	Stream studied for fish community number and name	Surrogate period of record	Mean daily streamflow statistics in cubic feet per second															Surrogate long term mean (ft^3/s)	1992-1994 mean (ft^3/s) at fish sites
			1988 water year			1989 water year			1990 water year			1991 water year			1992 water year				
			Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean		
01560000 Dunning Creek at Belden	01559795 Bobs Creek near Pavia	1940 -1994	2,060	12	167	3,300	18	294	1,440	16	186	2,200	11	252	1,100	11	135	230	264
01569800 Letort Spring Run near Carlisle	01571490 Cedar Run at Eberlys Mill	1979 -1994	87	22	35.7	126	20	35.5	114	26	40.8	135	21	42.8	92	17	28.3	43.1	45.6
01576500 Conestoga River at Lancaster	01576540 Mill Creek near Lyndon	1928 -1994	5,400	101	455	9,400	103	520	4,050	129	424	1,880	52	344	3,200	70	263	396	469
01573160 Quittapahilla Creek near Bellgrove	01573095 Bachman Run at Annville	1976 -1994	646	55	88.8	600	39	102	418	36	101	297	19	73.6	316	44	77.3	106	121
01564500 Aughwick Creek near Three Springs	01564997 Kishacoquillas Creek at Lumber City	1939 -1994	4,330	10	185	4,820	12	295	1,600	7.7	150	2,340	5.2	250	1,940	8.7	105	244	269
01555500 E Mahantango Creek near Dalmatia	01555400 East Mahantango Creek at Klingerstown	1939 -1994	2,070	14	171	4,310	15	252	2,300	33	209	2,530	7.8	222	3,350	9.3	155	226	267
01575000 South Branch Codorus Creek near York	01577300 Muddy Creek at Muddy Creek Forks	1928 -1994	2,010	.86	97.2	2,880	1.2	99.2	1,290	12	110	856	6.6	94.1	1,330	7.0	64.4	113	149

Mean daily streamflows for the long-term surrogate streams (1940-94) and study streams (1992-94) are provided to indicate the hydrologic conditions that existed during the data-collection period (table 3). The 1992-94 mean streamflows were higher than the long-term means at all principal reaches. However, the differences in the two means were small—ranging from 6 to 32 percent. On the basis of an analysis of the streamflow alone, the sampled stream conditions are considered representative of long-term hydrologic conditions.

Fish Community Data Collection and Data Analysis

Collections of fish were completed from June 1993 to June 1995 on an annual basis at the principal reaches (table 1) totaling 21 samples. An additional two reaches were sampled at Bobs Creek and East Mahantango Creek in June 1994 to gain insight into the degree of reach to reach variability totaling four additional samples (Meador and others, 1993a). Three more reaches were sampled in the Cedar Run watershed. This resulted in a data base consisting of 28 samples.

All reaches were wadable and sampled with either of two types of electrofishing gear—a pulsed direct current (DC) backpack unit or a tow barge also using pulsed DC. The gas-operated backpack electrofishing unit was operated in the DC mode with a voltage range of 150 to 700 volts and at 2 to 4 amperes at 60 cycles depending on the specific conductance of the stream to be sampled. Two passes were conducted in an upstream direction over reaches that ranged from 160 to 220 m (188 m average). Pass times ranged from 1,480 to 3,644 seconds for the first pass and 823 to 2,572 seconds for the second pass. The tow barge electroshocker was operated in the DC phase with voltages ranging from 150 to 1,000 volts depending on the specific conductance and at 2 to 4 amperes at 60 cycles. Two passes were completed in an upstream direction with reach lengths ranging from 100 to 303 m (244 m average). Pass times ranged from 1,202 to 6,900 seconds for the first pass and from 1,119 to 3,300 seconds for the second pass.

At all reaches, a minnow seine was employed for a follow-up collection in the riffle habitats. The seine was 1.2 m by 3.0 m with a 3.2 mm nylon mesh and placed in a stationary position in flowing water while immediately upstream the substrate was disturbed by kicking. The number of kicks varied from 4 to 12, and total sampling times ranged from 15 to 36 minutes.

Fish were identified in the field by the authors and by Charles Dix, Normandeau Associates, Spring City, Pa. Selected specimens were retained for reference and field verification. Dr. Robert F. Denoncourt, formerly of York College, Pa., conducted taxonomic verifications in the laboratory. A voucher collection currently resides at the USGS, Water Resources Division, Lemoyne, Pa.

Statistical Analyses

Two data sets were used to determine the relation between the environment and fish communities of the seven streams in this study; a fish data set and a data set of the combined environmental variables. Each data set was analyzed separately to make the data sets smaller and more interpretable. The smaller data sets were then analyzed together to show the relation between fish communities and their environment. For a basic analysis approach see the Appendix. A detailed approach follows.

A clustering technique to describe fish-species composition was used to determine if the 3 years of data collection (1993-95) were similar and how the reaches grouped. TWINSPAN constructs a two-way table by identification of differential species (Hill, 1979a). This technique is recommended because of its effectiveness and robustness as a polythetic hierarchical classification technique based on abundance data leading to less misclassification due to “noise” than typical monothetic techniques that are based on presence/absence data (Gauch, 1982). Hill (1979a) described three steps that are involved in the dichotomy of TWINSPAN. The first step is reciprocal averaging, which makes a crude dichotomy. The second step is a refined ordination derived from the reciprocal averaging by identification of differential species. The third step shows the indicator species that were the basis of the refined ordination.

A Jaccard coefficient of community, which measures the degree of similarity in taxonomic composition between two reaches by using presence or absence of taxa to differentiate between highly similar collections (Jaccard, 1912), also was calculated. This method was used to show similarity between the years and additional reaches sampled in 1994. This is a more conventional method for determining community similarity and was used to support the TWINSPAN analysis.

Fish communities were analyzed by use of a detrended correspondence analysis (DCA). DCA produces site scores on the basis of the fish communities at each reach by showing a unimodal response curve to environmental axes (Ter Braak, 1985), removing nonlinear dependencies between axes (Hill and Gauch, 1980), and eliminating the arch effect of the species (Gauch, 1982). Elimination of the arch effect is accomplished by dividing the first axis into segments and re-centering the reaches in each segment (Palmer, 1996). This analysis was performed to obtain linear site scores for use in a linear regression to assess which environmental variables best correlate to the species at each reach.

The environmental data set (table 4) required reduction to a manageable and interpretable size before being regressed with the DCA site scores and being used in the final canonical correspondence analysis (CCA). The number of variables must be less than the number of reaches otherwise colinearity will be found within the data set. This colinearity is typically between all variables after the threshold number of variables is reached. This colinearity is not legitimate but rids the program of too many variables by clumping any variables past the maximum allowed. This maximum must be one less than the number of reaches in the data set.

Two steps were completed to reduce the environmental variables before regression with the DCA site scores could be applied. First, the Shapiro-Wilk test was used to assess normality of the environmental variables (SAS Institute, Inc., 1990). The Shapiro-Wilk statistic is obtained by dividing the square of an appropriate linear combination of the sample order statistics by the usual symmetric estimate of variance (Klemm and others, 1990).

Second, Spearman-Rank correlation was used to reduce the environmental variables. This approach was used to assess potential multicolinearity among the environmental variables. When variables are strongly correlated with each other, the different effects of these variables on the community cannot be separated and the canonical coefficients become unstable (Ter Braak, 1986). After sets of correlated variables were determined, the normality scores that were generated from the Shapiro-Wilk test were applied. The normality scores were used to choose the more appropriate variable to be the surrogate variable. The remaining surrogate variables were subjected to a linear regression against the site scores generated by the DCA of the fish communities. Those variables with $p > 0.5$ and $r > 0.3$ were retained for further analysis.

A CCA was used to relate fish-community composition and the principal reaches to environmental variables. This technique constrains the ordination axes forcing them to be linear combinations of the environmental variables (Ter Braak, 1986). This linear

Table 4. *Environmental variable groups, subgroups, specific variable, and unit of measure*

Environmental variable group	Environmental variable subgroup	Specific environmental variables	Unit of measure
Habitat	basin	drainage area	square kilometers
	basin	drainage density	none
	basin	drainage shape	none
	basin	basin relief	meter
	basin	percent agriculture	percent
	basin	percent urban	percent
	basin	percent forested	percent
	segment	segment length	kilometer
	segment	elevation	meter
	segment	sideslope gradient	meter
	segment	segment gradient	none
	segment	stream order	none
	reach	reach length	meter
	reach	mean bank width	meter
	reach	mean floodplain width	meter
	reach	mean canopy angle	degree
	reach	mean embeddedness	none
	reach	bank stability	none
	reach	bank erosion	none
	reach	percent rubbish	percent
	reach	percent boulder	percent
	reach	percent overhanging vegetation	percent
	reach	percent undercut banks	percent
	reach	percent woody snags	percent
	reach	percent emergent macrophytes	percent
	reach	percent submerged macrophytes	percent
	reach	dominant bottom substrate	none
	reach	subdominant bottom substrate	none
	reach	dominant bank substrate	none
	reach	subdominant bank substrate	none
	reach	BSI (bank stability index)	none
	reach	dominant Wolman pebble size	none
	reach	subdominant Wolman pebble size	none
Hydrology	basin	drainage texture	none
	basin	stream length	kilometer
	basin	annual precipitation	centimeter
	segment	channel sinuosity	none
	reach	mean channel width	meter
	reach	mean thalweg depth	centimeter
	reach	mean velocity	centimeters per second
	reach	discharge	cubic meter per second
	reach	width to depth ratio	none
Water chemistry	reach	specific conductance	microsiemens per centimeter
	reach	temperature	celsius
	reach	pH	standard units
	reach	dissolved oxygen (DO)	milligrams per liter
	reach	chlorophyll *a*	milligrams per square meter
	reach	chlorophyll *b*	milligrams per square meter

Table 4. *Environmental variable groups, subgroups, specific variable, and unit of measure —Continued*

Environmental variable group	Environmental variable subgroup	Specific environmental variables	Unit of measure
Water chemistry—Continued	reach	ash free dry mass	grams per square meter
	reach	total phosphorus	milligrams per liter as phosphorus
	reach	nitrate	milligrams per liter as nitrogen
	reach	ammonia	milligrams per liter as nitrogen
	reach	dissolved organic carbon (DOC)	milligrams per liter as carbon
	reach	dissolved phosphorus	milligram per liter as phosphorus
	reach	suspended sediment	milligrams per liter
	reach	percent dissolved oxygen (percent DO) saturation	percent

combination of environmental variables best explains the dispersion of the species (Ter Braak, 1987). These axes are linear combinations of the environmental variables with which the species are directly related (Dixit and others, 1991) and constrained (Frenzel, 1996). Also, CCA is an extension of correspondence analysis (reciprocal averaging), which shows variation from species occurrence or abundance data by combining aspects of regular ordination and direct gradient analysis (Ter Braak, 1986). Not all measured environmental variables are equally important and can be combined to form a synthetic environmental gradient that better separates the species niches (Ter Braak and Verdonschot, 1995).

Forward selection in CCA was used to determine the most influential environmental variables to the fish communities. Forward selection identifies a minimal number of environmental variables to help explain the biological communities (Fritz and others, 1993). Rare taxa were down-weighted to prevent biasing the analysis (Hill, 1979b). Down-weighting is based on the “frequency of the commonest species divided by five” and anything less than this value is considered rare (North Carolina Ecology Group, 1996; Ter Braak, 1988; Hill, 1979b). The final CCA shows the relation between the environmental variables and the fish communities at each reach (Austin, 1968; Williams, 1976; Gittins, 1979; Gauch, 1982). Each environmental arrow (eigenvector) is an axis in the diagram with its length showing its importance and extending through the origin equally in the negative direction. The environmental gradient scores were correlated to the axes scores to show the strength of the relation between the environmental gradient and the axes. A perpendicular can be dropped from a species to the environmental gradient to show the relation between the species and that particular environmental gradient (Ter Braak, 1986). The main axes are a combination of the environmental variables that best define the site positions on the CCA diagram.

FISH COMMUNITIES AND THEIR RELATION TO SELECTED PHYSICAL AND CHEMICAL CHARACTERISTICS OF STREAMS

Characteristics of Fish Communities

A total of 33,143 fish were collected in the 28 samples. Thirty-nine species were collected from eight families and confirmed by a taxonomic specialist (table 5). The Cyprinidae (minnows) were represented by the greatest number of species (17) followed by the Centrarchidae (sunfishes) with 7 species and the Percidae (perches and darters) with 4 species.

The most abundant and frequently collected species were the blacknose dace (*Rhinichthys atratulus*) with 8,353 individuals from 26 samples, white sucker (*Catostomus commersoni*) with 4,600 individuals from 27 samples, and the sculpins (*Cottus* spp) with 3,246 individuals from 11 samples. The sculpins were combined because of taxonomic difficulties in separating slimy sculpins (*C. cognatus*) from mottled sculpins (*C. bairdi*) in the field. Together, these species made up 49 percent of the total fish collected. The least abundant species were yellow perch (one individual at one reach), golden shiner (one individual from one reach), banded killifish (four individuals from one reach), and largemouth bass (four individuals from a combination of four reaches). For all years at all reaches, the cyprinids made up 64.3 percent, the catostomids 15.7 percent, and the cottids 9.8 percent of the total numbers of fish collected.

TWINSPAN and Jaccard's coefficient of community were used to show similarities between the years of collection at each reach and comparison reach studies (fig. 2, table 6). TWINSPAN split the reaches into those from the same stream with the 3 years and additional reaches of fish-community data grouping together. Jaccard's coefficient showed the reaches as having 60 percent or greater similarity with the same reach for the different years and reaches. These analyses show 1993 to be representative of the 3 years of data collected and the related reaches. Frenzel and Swanson (1996) used the same approach and came to a similar conclusion.

Thirty-three species collected in 1993 were analyzed in the fish community DCA. Five additional species were collected between 1994 and 1995 but totaled less than 1 percent of the communities. The first axis had an eigenvalue of 0.6983 and the second of 0.1890 (table 7). These two axes explained 46.3 percent of the variance at the reaches according to the fish species. Of the total variance at the principal reaches, 47.1 percent was explained by the differences in the fish communities at each reach (fig. 3).

Table 5. *Fish species collected during 1993-95 at the streams studied for the assessment of fish communities in the Lower Susquehanna River Basin, Pennsylvania and Maryland*

[X, species collected during the 3 years of study; (), number of individual fish collected in 1993; nomenclature is consistent with Robins and others, 1991]

Fish species		Stream name						
Common name	Scientific name	Cedar Run at Eberlys Mill, Pa.	Mill Creek at Eshelman Mill Road near Lyndon, Pa.	Bachman Run at Annville, Pa.	Kishacoquillas Creek at Lumber City, Pa.	Bobs Creek near Pavia, Pa.	East Mahantango Creek at Klingerstown, Pa.	Muddy Creek at Muddy Creek Forks, Pa.
Carps and Minnows	Cyprinidae							
central stoneroller	*Campostoma anomalum*					X(1)	X(0)	X(69)
satinfin shiner	*Cyprinella analostana*		X(8)				X(8)	X(7)
spotfin shiner	*Cyprinella spiloptera*		X(62)				X(0)	X(1)
common carp	*Cyprinus carpio*		X(1)					
cutlips minnow	*Exoglossum maxillingua*		X(9)		X(394)	X(17)	X(113)	X(21)
common shiner	*Luxilus cornutus*				X(185)		X(41)	X(275)
pearl dace	*Margariscus margarita*	X(168)		X(1)				
river chub	*Nocomis micropogon*					X(0)	X(82)	X(194)
golden shiner	*Notemigonus crysoleucas*		X(0)					
spottail shiner	*Notropis hudsonius*		X(58)		X(92)		X(106)	X(20)
swallowtail shiner	*Notropis procne*		X(20)				X(5)	
rosyface shiner	*Notropis rubellus*						X(16)	X(11)
bluntnose minnow	*Pimephales notatus*		X(8)		X(30)		X(64)	X(10)
blacknose dace	*Rhinichthys atratulus*	X(470)	X(1)	X(626)	X(437)	X(228)	X(7)	X(57)
longnose dace	*Rhinichthys cataractae*		X(0)		X(209)	X(51)	X(44)	X(55)
creek chub	*Semotilus atromaculatus*		X(0)	X(6)	X(1)	X(1)	X(16)	X(20)
fallfish	*Semotilus corporalis*				X(0)		X(142)	X(11)
Suckers	Catostomidae							
white sucker	*Catostomus commersoni*	X(189)	X(506)	X(59)	X(808)	X(10)	X(100)	X(194)
northern hog sucker	*Hypentelium nigricans*		X(21)		X(25)		X(6)	X(47)
Bullhead catfishes	Ictaluridae							
yellow bullhead	*Ameiurus natalis*		X(17)		X(6)		X(1)	
brown bullhead	*Ameiurus nebulosus*		X(1)					
margined madtom	*Noturus insignis*		X(0)		X(13)		X(76)	X(23)
Trouts	Salmonidae							
rainbow trout	*Oncorhynchus mykiss*			X(7)	X(4)	X(0)	X(5)	X(2)
brown trout	*Salmo trutta*	X(77)		X(10	X(24)	X(38)	X(1)	X(7)
brook trout	*Salvelinus fontinalis*			X(2)		X(32)	X(0)	
Killifishes	Cyprinodontidae							
banded killifish	*Fundulus diaphanus*		X(0)					

Table 5. *Fish species collected during 1993-95 at the streams studied for the assessment of fish communities in the Lower Susquehanna River Basin, Pennsylvania and Maryland—Continued*

[X, species collected during the 3 years of study; (), number of individual fish collected in 1993; nomenclature is consistent with Robins and others, 1991]

Fish species		Stream name						
Common name	Scientific name	Cedar Run at Eberlys Mill, Pa.	Mill Creek at Eshelman Mill Road near Lyndon, Pa.	Bachman Run at Annville, Pa.	Kishacoquillas Creek at Lumber City, Pa.	Bobs Creek near Pavia, Pa.	East Mahantango Creek at Klingerstown, Pa.	Muddy Creek at Muddy Creek Forks, Pa.
Sculpins	Cottidae							
sculpin	*Cottus spp.*			X(45)	X(2)	X(289)		
Sunfishes	Centrarchidae							
rock bass	*Ambloplites rupestris*		X(20)		X(60)	X(1)	X(17)	X(15)
redbreast sunfish	*Lepomis auritus*		X(146)				X(0)	X(4)
green sunfish	*Lepomis cyanellus*		X(0)				X(0)	X(0)
pumpkinseed	*Lepomis gibbosus*		X(11)		X(2)		X(0)	
bluegill	*Lepomis macrochirus*		X(0)	X(0)	X(3)		X(10)	
smallmouth bass	*Micropterus dolomieu*		X(14)				X(12)	X(17)
largemouth bass	*Micropterus salmoides*		X(0)		X(0)		X(0)	
Perches	Percidae							
tessellated darter	*Etheostoma olmstedi*		X(5)	X(30)	X(68)		X(40)	X(32)
banded darter	*Etheostoma zonale*						X(15)	X(3)
yellow perch	*Perca flavescens*					X(0)		
shield darter	*Percina peltata*						X(2)	X(11)
Total number of species collected:		4	25	10	20	13	31	25

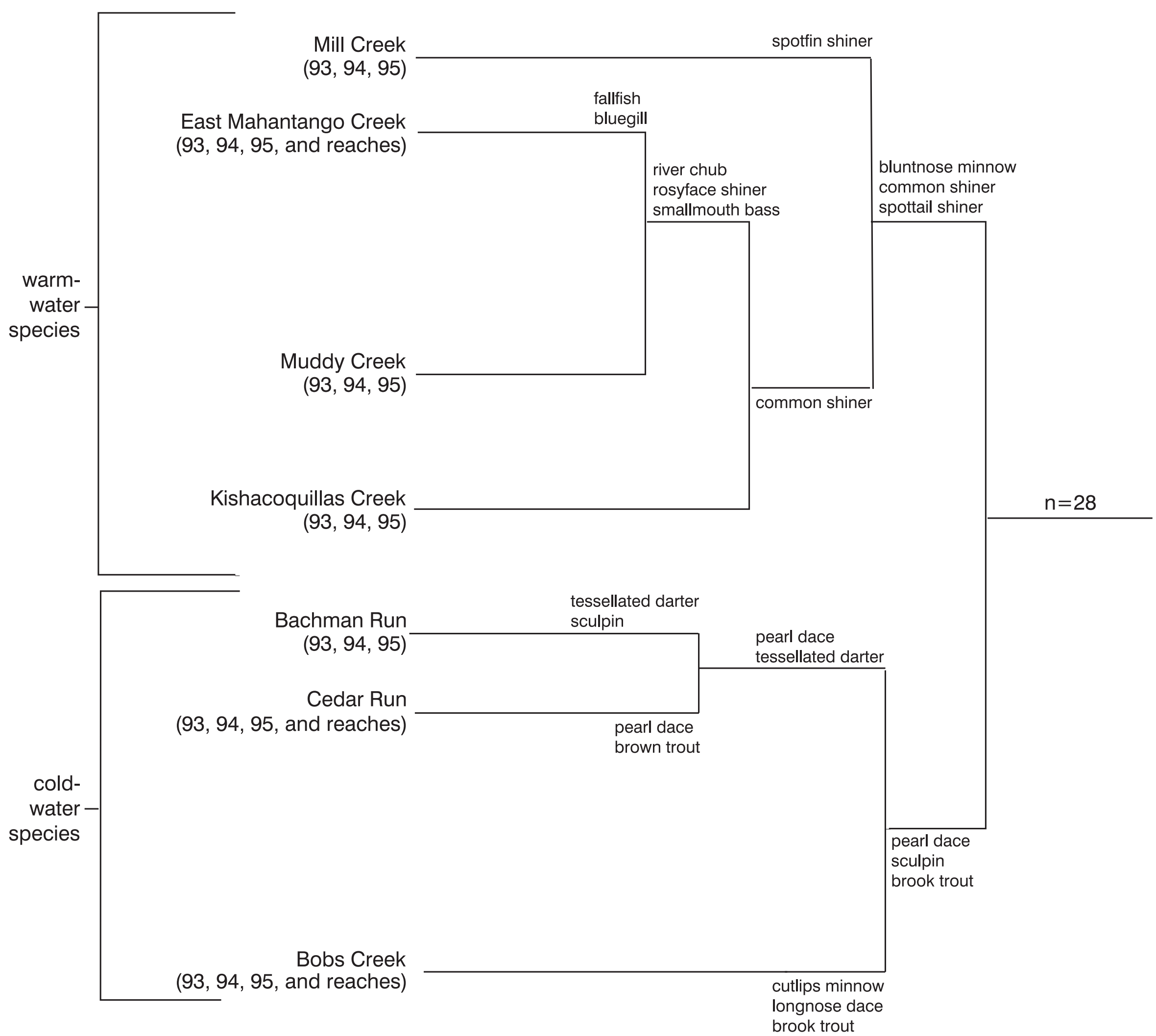

Figure 2. TWINSPAN analysis of fish communities at the principal reaches of the Lower Susquehanna River Basin from 1993 to 1995.

Table 6. *Jaccard coefficient of community between years and reaches in percent similarity of taxonomic composition for the streams in the Lower Susquehanna River Basin, Pennsylvania and Maryland*

[--, no comparisons were made]

Stream name	1993 & 1994	1993 & 1995	reach 1 & 1993	reach 2 & 1993	Cedar Run 1993
Bobs Creek (reach 3)[1]	69	80	64	64	--
East Mahantango Creek (reach 3)[1]	77	71	78	75	--
Muddy Creek (reach 1)[2]	84	83	--	--	--
Kishacoquillas Creek (reach 2)[3]	89	89	--	--	--
Mill Creek (reach 1)[2]	73	60	--	--	--
Bachman Run (reach 2)[3]	89	89	--	--	--
Cedar Run (reach 3)[1]	100	100	--	--	--
Unnamed Tributary to Unnamed Northern Tributary to Cedar Run (reach 1)[4]	--	--	--	--	100
Unnamed Northern Tributary to Cedar Run	--	--	--	--	80
Cedar Run at Shiremanstown (reach 1)[4]	--	--	--	--	100

[1] Reach 3 was sampled in 1993, 1994, and 1995.
[2] Reach 1 was sampled in 1993, 1994, and 1995.
[3] Reach 2 was sampled in 1993, 1994, and 1995.
[4] Sampled in 1994 only.

Table 7. *Summary of detrended correspondence analysis (DCA) of fish communities*

Summary	Axis 1 loadings	Axis 2 loadings
Eigenvalue	0.6983	0.1890
Proportion of total variance (percent)	36.4	9.9
Cumulative proportion (percent)	36.4	46.3

The first axis (fig. 3) showed the gradient from warm- to cold-water species. The warmer streams were dominated by banded darter, rosyface shiner, fallfish, margined madtom, river chub, bluegill, shield darter, satinfin shiner, smallmouth bass, bluntnose minnow, and stoneroller. These species are listed from the most to the least correlated along the first axis. The cooler streams were dominated by brook trout, sculpin, brown trout, pearl dace, and blacknose dace. The first axis explained 36.4 percent of the 47.1 percent total variance (table 7) that differentiates the reaches based only on fish communities. This same trend was seen in the TWINSPAN analysis (fig. 2).

The second axis (fig. 3) further separated the warm-water species. Muddy Creek had a lower elevation, gradient, basin relief, velocity, and DOC than the reach furthest away on the second axis, East Mahantango Creek. The Muddy Creek side was dominated by stoneroller, shield darter, common shiner, northern hog sucker, and river chub. Those species associated with the East Mahantango Creek side were bluegill, banded darter, bluntnose minnow, and margined madtom. The second axis explained 9.9 percent of the total variance between the reaches (table 7).

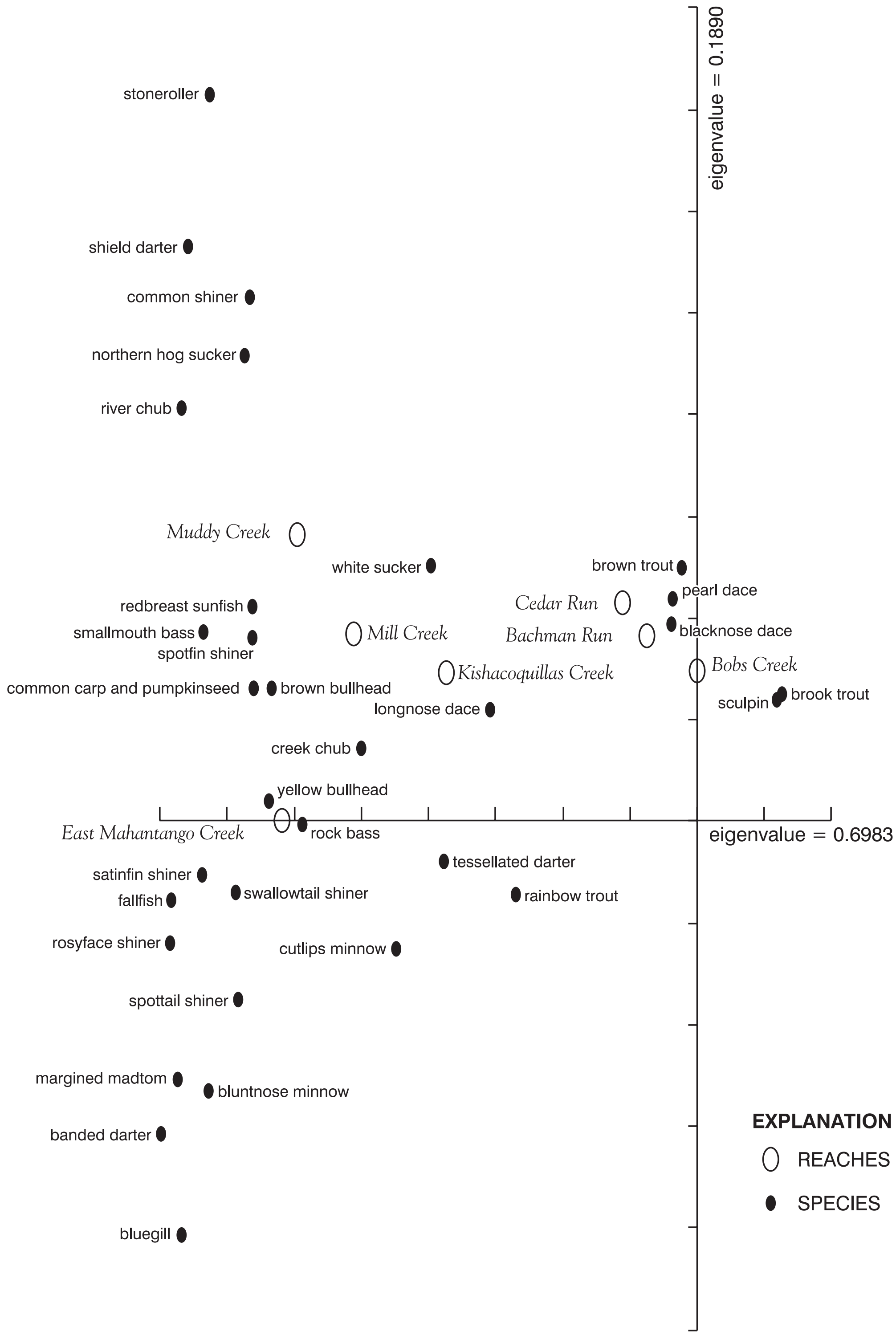

Figure 3. Detrended correspondence analysis (DCA) biplot of fish species in relation to reaches in the Lower Susquehanna River Basin in 1993.

Those species deemed important in the fish DCA (fig. 3) were also many of the species that were preferential species used in TWINSPAN (fig. 2) to produce the dichotomies. The warm-water species in common between the two methods of analysis are rosyface shiner, fallfish, river chub, bluegill, smallmouth bass, bluntnose minnow, and common shiner. The cold-water species are sculpin, brook trout, pearl dace, and brown trout.

Relation of Physical and Chemical Gradients to Fish Communities

The original environmental list of 56 variables was too large to be interpreted by CCA. Surrogate variables were chosen through a Spearman-Rank correlation analysis to regress against the DCA site scores for the first axis. A total of 23 environmental variables were correlated with the DCA first axis site scores (table 8). Of these 23 environmental variables, 12 were correlated to the DCA first axis site scores. These 12 environmental variables were introduced into the CCA analysis and forward selection was used to determine the 6 final variables. These six environmental variables were suspended sediments, mean canopy angle, mean channel width, mean water temperature, DOC, and BSI. CCA arranges reaches along the CCA axes according to the fish communities and their related environmental variables. These environmental variables act together (Hawks and others, 1986) to show a relation between the fish communities and environmental variables.

Table 8. *Correlation scores for the detrended correspondence analysis (DCA) first axis scores and environmental variables*

Environmental variables	r-value	p-value
segment length	0.14	0.74
drainage texture	.34	.46
stream length	.69	.08
basin relief	.17	.68
annual precipitation	.01	.97
mean channel width	.83	.02
mean canopy angle	.48	.28
mean specific conductance	.2	.66
mean temperature	.88	.01
mean pH	.09	.84
mean dissolved oxygen (DO)	.78	.04
chlorophyll *a*	.39	.38
chlorophyll *b*	.13	.79
nitrates	.06	.90
dissolved organic carbon (DOC)	.33	.48
suspended sediment	.41	.36
embeddedness	.08	.87
vegetative bank stability	.24	.60
percent boulder	.28	.54
percent overhanging vegetation	.04	.93
percent woody debris	.63	.13
percent forested	.46	.30
bank stability index (BSI)	.51	.24

The CCA (fig. 4) for the Lower Susquehanna River Basin reaches shows the first axis explains 37 percent of the variance and is dominated by the environmental variables of temperature (r^2 = 0.7695) and mean channel width (r^2 = 0.7128), which are related to the stream size. All correlations to the first four CCA axes are listed in table 9. The small

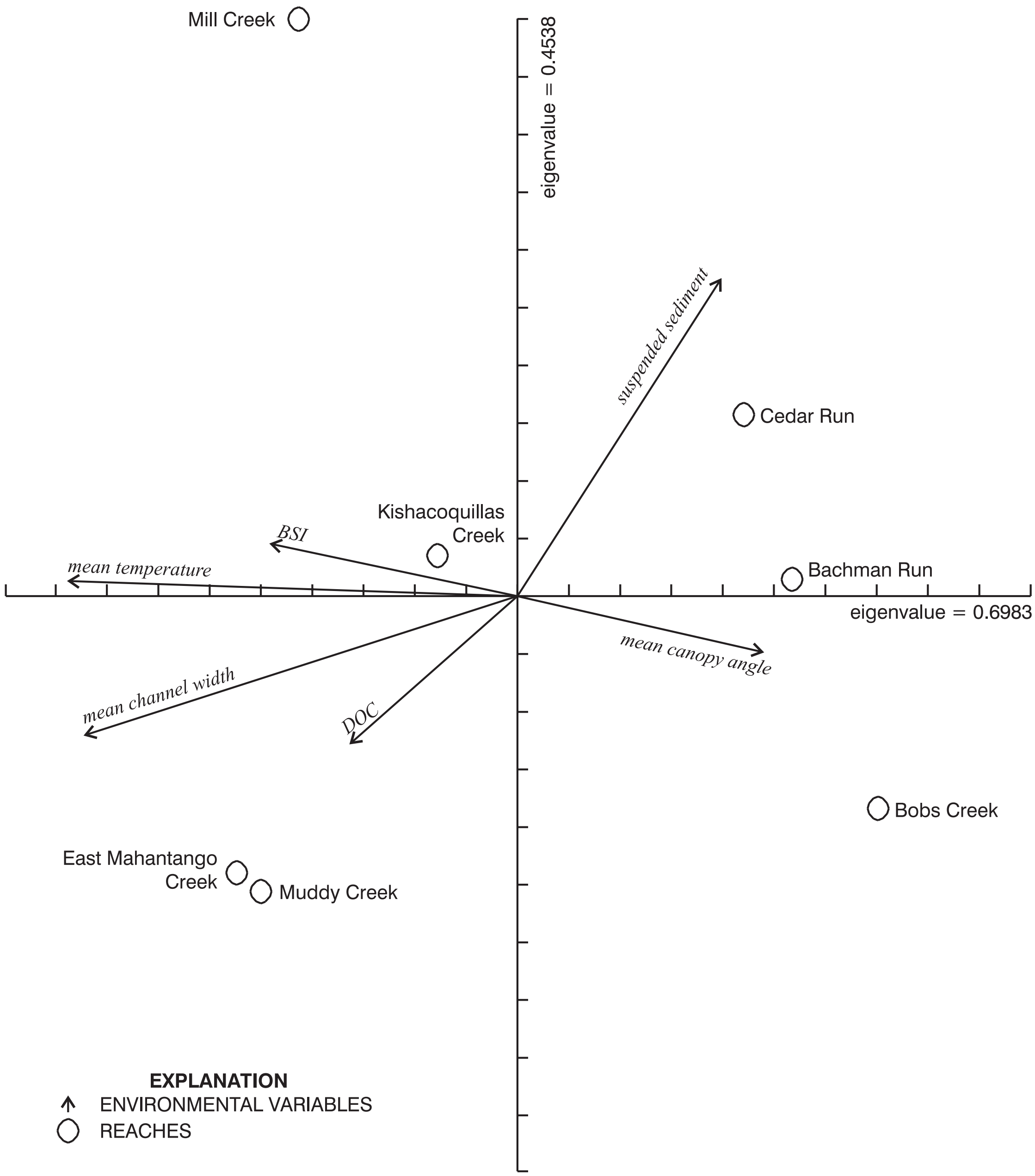

Figure 4. Canonical correspondence analysis (CCA) biplot of final environmental variables in relation to the principal reaches in the Lower Susquehanna River Basin in 1993.

streams—Cedar Run, Bachman Run, and Bobs Creek—had channel widths ranging from 7 to 9 m. These streams also had the lowest temperatures ranging from 13 to 17°C. The larger streams—Kishacoquillas Creek, Mill Creek, East Mahantango Creek, and Muddy Creek—had channel widths ranging from 13.4 to 19.8 m and temperatures ranging from 18 to 23°C. Temperature correlated negatively with segment gradient and positively with drainage area (table 10). An inverse relation exists between canopy and temperature. As drainage area increases, canopy and segment gradient decrease. These in turn cause the water temperature to increase. Goldman and Horne (1983) also found that temperature tended to increase with less gradient and canopy and with larger substrate. Additionally, Smith (1980) suggests that wider streams with less canopy are generally warmer than those that are shaded by trees, shrubs, and high steep banks. The stream size is the most influential variable to the fish communities studied in the Lower Susquehanna River Basin.

Table 9. *Correlation (r^2) of environmental variables to the first four canonical correspondence analysis (CCA) axes*

Environmental variable	Axis 1	Axis 2	Axis 3	Axis 4
mean temperature	0.7695	0.0027	0.0646	0.1331
bank stability index (BSI)	.2504	.0066	.0366	.4622
mean canopy angle	.2301	.0106	.6375	.0089
suspended sediment	.1513	.2971	.4940	.0030
dissolved organic carbon (DOC)	.1148	.0726	.0143	.4282
mean channel width	.7128	.0547	.0057	.0229

Table 10. *Environmental variables used in canonical correspondence analysis (CCA) and the associated variables from Spearman-Rank correlation*

Environmental variable used in CCA	Correlated variable	r^2-value	p-value
water temperature	segment gradient	-0.8365	0.02
	drainage area	.7857	.04
bank stability index (BSI)	floodplain width	-.9274	.003
	ammonia	.7572	.05
	dominant bottom substrate	-.7748	.04
	subdominant Wolman pebble size	-.9258	.003
mean canopy angle	reach length	-.8571	.01
	percent submerged macrophytes	.7906	.03
suspended sediment	specific conductance	.8929	.01
	percent undercut banks	.8367	.02
	dominant bottom substrate	-.8469	.02
	percent submerged macrophytes	.7906	.03
dissolved organic carbon (DOC)	sinuosity	-.8214	.02
	basin relief	.7638	.05
	bank erosion	-.7559	.05
mean channel width	stream order	.9258	.002
	drainage area	.8214	.02
	percent submerged macrophytes	-.7906	.03
	percent undercut banks	-.7769	.04

Suspended sediment was the variable most strongly correlated with the second axis (r^2 = 0.2971), but even this correlation was weak. All the environmental variables were weakly correlated to the second axis, which accounted for 24 percent of the variance and caused the separation of Mill Creek from the other reaches. Suspended sediment is correlated with specific conductance, percent undercut banks, dominant bottom substrate, and percentage of submerged macrophytes. Mill Creek, Bachman Run, and Cedar Run contained high concentrations of suspended sediments, 40 to 96 mg/L, as compared to 4 to 22 mg/L, for the other streams. These same reaches also had higher specific conductance and a higher percentage of undercut banks and submerged macrophytes; two of the three reaches had smaller substrate. Bottom material from Mill Creek consisted of mostly bedrock; Cedar and Bachman Runs were predominantly composed of gravel and cobble. Submerged macrophytes were found only at Cedar Run and Bachman Run. All these environmental variables may account for some of the separation seen between Mill Creek and Cedar and Bachman Runs in the CCA analysis.

Suspended sediment (r^2 = 0.4940) and canopy angle (r^2 = 0.6375) were correlated with the third axis of the CCA, which explained 18 percent of the variance (fig. 4). The combination of these variables also suggested that Mill Creek is distinctly different from Cedar and Bachman Runs. The streams to the left of the CCA origin have less canopy cover than do those to the right of the origin. Canopy cover is a surrogate variable for reach length and submerged macrophytes (table 10). The reach length varied accordingly with the channel width of the streams with one exception, Bobs Creek. The wider stream had less canopy cover. Also, the two streams with submerged macrophytes grouped together along the canopy gradient.

BSI (r^2 = 0.4622) and DOC (r^2 = 0.4282) were most highly correlated with the fourth axis and accounted for 10 percent of the variance (fig. 4). All the streams had rather similar BSI's ranging from 2.1 to 3.2. Bobs Creek was typically more stable than Kishacoquillas and Muddy Creeks. DOC is a measure of the organic carbon dissolved in the water (Drever, 1988). Higher concentrations of DOC, which are typically associated with higher streamflows, are an energy source for biota (Likens and Bormann, 1995). DOC concentrations also vary with stream size, climate, and vegetation within the basin (Thurman, 1985). East Mahantango Creek and Kishacoquillas Creek had the highest mean DOC concentrations (13 mg/L); Bachman Run had the lowest concentration (1.5 mg/L).

The variables of suspended sediment and BSI appear to function independently (fig. 4). Overall, limestone streams had higher suspended-sediment concentrations than did freestone streams. Although Mill Creek has the most stable bank condition among the limestone streams, it exhibits the greatest suspended sediments. This is evidence of the predominant sediment source from agricultural runoff. The freestone streams also exhibit a similar condition in that Bobs Creek has higher velocities and greater bank erosion than the larger freestone streams but has little agricultural runoff and therefore lower suspended sediments.

Kishacoquillas Creek exhibited features of both limestone and freestone streams (fig. 4). Temperature, canopy angle, suspended sediments, and BSI values were neither closer to the freestone nor the limestone stream values. However, Kishacoquillas Creek is the widest of the streams and has the highest DOC concentrations. These two variables influence the Kishacoquillas Creek enough to pull the stream's position on the CCA closer to the freestone streams in its fish-community composition.

Reaches in the CCA were arranged according to the fish communities and the environmental variables influencing these communities. Some species appeared to be non-specific in their habitat requirements and were found in a wide variety of streams. Conversely, some species appeared to have very specific environmental requirements.

Fish communities that include a combination of pearl dace, brown trout, brook trout, sculpins, and/or blacknose dace are typical of streams that tend to be narrow, have good canopy cover, and have a lower mean temperature (cold-water streams). In the Lower Susquehanna River Basin, these streams were Bobs Creek, Bachman Run, and Cedar Run. The wider, warmer streams had more diverse fish communities. Instead of just 4 to 13 species in a reach, the larger streams had communities of 20 to 31 species (table 5). The CCA results suggest that larger streams in the Lower Susquehanna River Basin provide additional habitat capable of supporting a greater diversity of species.

The TWINSPAN analysis (fig. 2) defined three basic communities with different species composition. Each community was identified by "preferential species." Those species defined both the community and the environmental conditions required by that community.

The first community that was defined by the presence of pearl dace is from cold-water, limestone streams. Pearl dace were collected in abundance at Cedar Run and one specimen was collected at Bachman Run (fig. 5), but none were found in the other five streams. Cedar Run and Bachman Run had different physical and water-quality characteristics than the other streams in that they are limestone, spring fed, cold-water streams with moderate gradient, pools, and aquatic vegetation. Pearl dace are typically found in small, clear, spring-fed streams where pools and aquatic vegetation occur (Smith, 1985; Jenkins and Burkhead, 1994). Bachman Run had higher nutrient concentrations and the substrate was more embedded than Cedar Run. Even though Bobs Creek is a freestone, cold-water stream, the mean pH was 7.2; the mean pH at Bachman and Cedar Runs was 8.1 and 8.0, respectively. Both Cedar Run and Bachman Run have aquatic vegetation and pools, are spring fed, and have higher pH. The TWINSPAN (fig. 2), DCA (fig. 3), and CCA (fig. 5) all showed Bobs Creek as having a different fish community than Cedar and Bachman Runs.

The second community was defined by brook trout that were collected at Bobs Creek and Bachman Run. Bobs Creek is a headwater, forested stream with a mean temperature of 14°C. This was the coldest stream sampled. The suspended-sediment concentration was considered minimal at 4 mg/L. The mean pH was 7.2. This stream has a gravel bottom and a DO concentration near saturation. Brook trout are found in water with year-round temperatures between 14-16°C, high concentrations of DO, flowing water, little silt and fine particles, a pH between 7.0 and 8.0, and bottom substrate dominated by gravel and rubble (Smith, 1985; Shiffer, 1990; Jenkins and Burkhead, 1994). The largest population of brook trout (4.8 percent) was collected at Bobs Creek (fig. 5). Brook trout made up 0.3 percent of the fish community at Bachman Run.

The third community was a warm-water community. The warm-water streams were defined by the presence of bluntnose minnow, common shiner, and spottail shiner. Bluntnose minnows and spottail shiners are found in small creeks and in larger creeks and rivers with a low gradient, pools, and backwater areas (Jenkins and Burkhead, 1994, Page and Burr, 1991). Common shiners are found in similar habitats as the bluntnose minnow and spottail shiner and also are found feeding in slower riffle areas (Jenkins and Burkhead, 1994; Page and Burr, 1991). This commonality of habitat is noted by the TWINSPAN (fig. 2), DCA (fig. 3) and the CCA (fig. 5). The DCA and CCA show the

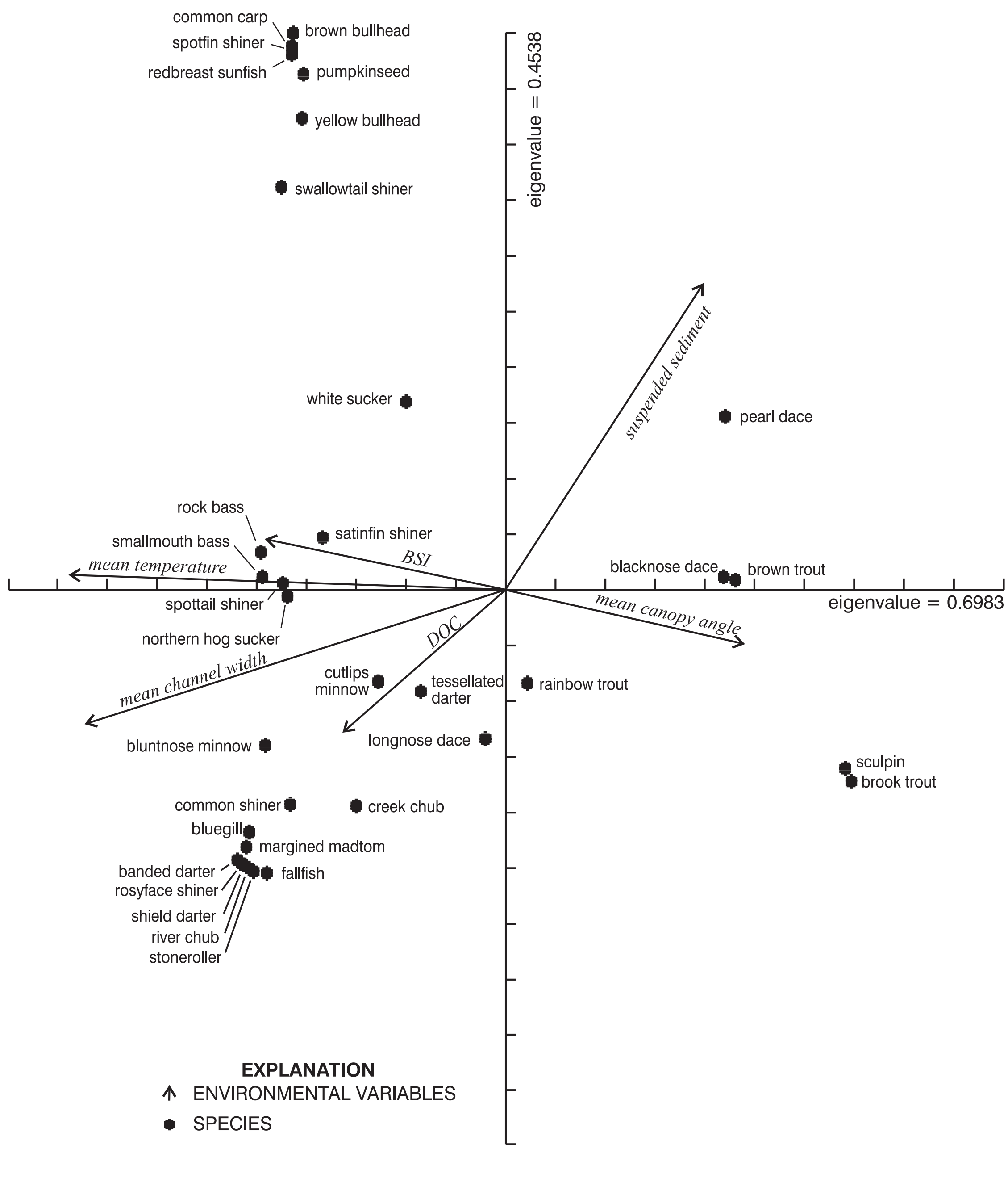

Figure 5. Canonical correspondence analysis (CCA) biplot of environmental variables in relation to fish communities in the Lower Susquehanna River Basin in 1993.

bluntnose minnow and spottail shiner more closely related by habitat than the common shiner, but all three species are found in warm-water streams in the Lower Susquehanna River Basin.

Other studies using a multivariate approach have yielded results similar to those reported here. Frenzel (1996) described channel width, water temperature, and canopy as important variables influencing fish communities in central Nebraska. Frenzel and Swanson (1996) reported specific conductance and canopy angle as important factors. Channel width, canopy cover, suspended sediment, and DOC were some of the stream-habitat variables that influenced the fish communities in the Red River of the North Basin of Minnesota and North Dakota (Goldstein and others, 1996). Ward and Kondratieff (1992) stated that water temperature, water discharge and velocity, substrate and suspended material, water chemistry, and vegetation were factors that potentially determined the distribution of biological communities. Water temperature and clarity were determined to be significant to fish communities of the Gandaki River of Nepal (Edds, 1993). Fish communities are influenced by the same basic habitat variables worldwide.

Multiple environmental gradients act in conjunction to define and alter community structure (Rakocinski and others, 1992). The previous discussion of the CCA shows multiple environmental gradients affecting the communities found at the principal reaches sampled in the Lower Susquehanna River Basin. This basin, with its habitat variables of temperature, BSI, canopy angle, suspended sediment, DOC, and channel width, showed results similar to those in other studies on fish community. Temperature seems to be the first variable to define the fish communities. Fish are first classified as warm- or cold-water species and further definition of communities continues from that broad classification.

SUMMARY

The environmental factors that influence fish-community composition were identified and studied in the Lower Susquehanna River Basin, which is one of 59 study units in the National Water Quality Assessment Program of the U.S. Geological Survey. Seven streams were selected for study on the basis of bedrock type and land use/land cover. Major importance was assigned to those areas with a majority of agricultural land use that is largely underlain by carbonate bedrock. Other factors considered in stream selection were areas in transition from agriculture to commercial, industrial, and residential land use. Habitat, hydrology, and water-quality information were collected at one or more reaches in these streams in conjunction with fish assessments.

A total of 33,143 fish were collected from the 28 samples during the 3-year intensive period from 1993 to 1995. Thirty-nine species were collected from eight families. The Cyprinidae (minnows) were represented by the greatest number of species (17), followed by the Centrarchidae (sunfishes) with 7 species, and by the Percidae (perches and darters) with 4 species.

The most abundant and frequently collected species were the blacknose dace (*Rhinichthys atratulus*), white sucker (*Catostomus commersoni*), and the sculpins (*Cottus* spp), in that order. Together these three species made up 49 percent of the total fish collected. The least abundant species were yellow perch, golden shiner, banded killifish, and largemouth bass. Cyprinids made up 64.3 percent of the total fish collected for all samples at the principal reaches over the 3 years, catostomids 15.7 percent, and cottids 9.8 percent.

Six environmental variables were shown to be associated with fish communities through TWINSPAN, correlation analysis, and canonical correspondence analysis (CCA). These variables are surrogates for other environmental variables that also affect the distribution of fish species at the principal reaches. Environmental variables in the defined groups of habitat, hydrology, and water quality act together to influence the composition of these fish communities. Temperature and channel width were the variables most strongly correlated with the first CCA axis and those that explained the greatest amount of variance in the fish communities. These variables were surrogates for segment gradient, drainage area, and stream order, which are all measurements of a size gradient. Stream size gradient is the most influential variable to the fish communities studied in the Lower Susquehanna River Basin.

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APPENDIX

An example step-by-step method for performing multivariate statistics

I. Set up data matrix with sites as columns and species or environmental variables as rows.

II. Convert matrix to FORTRAN format.

III. Cluster sites by using relative abundance of species and select those for further analysis based on the clustering pattern.

IV. Run a DCA on fish communities to obtain site scores and a distribution of species in relation to sites.

V. Check environmental data for normality.

VI. Transform non-normal data.

VII. Check for correlations among the environmental variables.

VIII. Remove all but one of the correlated variables.

   A. Variable retained was based on the probabilities of normal distribution.

   B. The remaining variable is a surrogate for those correlated to the remaining variable.

IX. Regress remaining environmental variables against DCA site scores.

X. Remove variables that have a low r-value.

XI. Run CCA on variables.

   A. If there are too many variables, use forward selection.

   B. Remove variables with a high inflation factor.

   C. General rule is that if the inflation factor is higher than 20, the variable is likely correlated with another variable and does not help in explaining the relationship (Ter Braak, 1988).

XII. Run CCA on final environmental variables and species data.