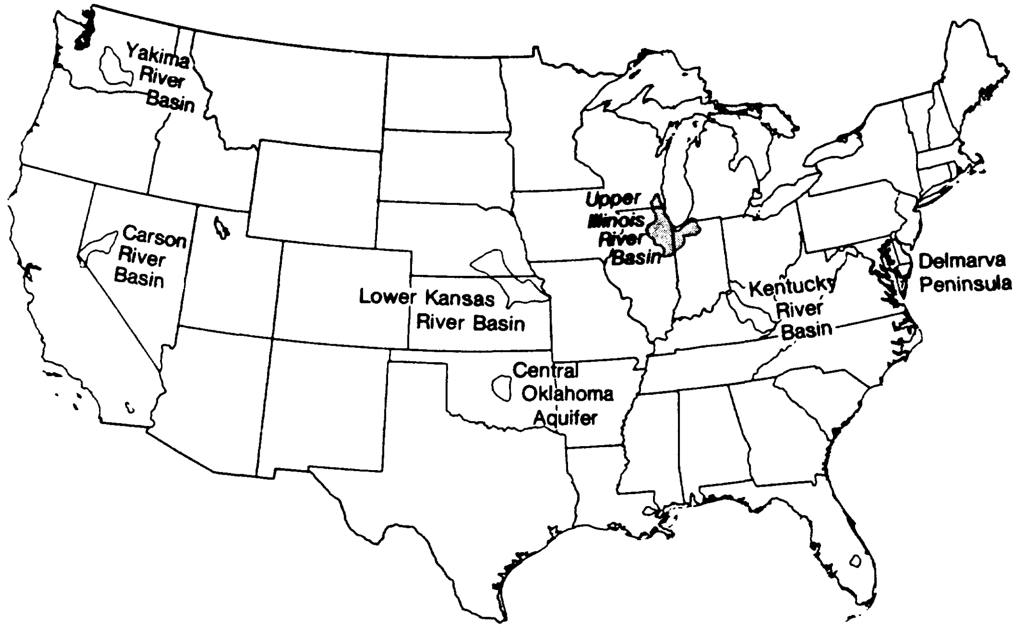
SURFACE–WATER–QUALITY ASSESSMENT OF THE UPPER ILLINOIS RIVER BASIN IN ILLINOIS, INDIANA, AND WISCONSIN: ANALYSIS OF RELATIONS BETWEEN FISH–COMMUNITY STRUCTURE AND ENVIRONMENTAL CONDITIONS IN THE FOX, DES PLAINES, AND DU PAGE RIVER BASINS IN ILLINOIS, 1982-84

by Peter M. Ruhl



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CONVERSION FACTORS, WATER-QUALITY UNITS, AND ABBREVIATIONS

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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.

Abbreviations used in this report:

AIBI	Alternate Index of Biotic Integrity
DCA	Detrended correspondence analysis
IBI	Index of Biotic Integrity
IDOC	Illinois Department of Conservation
IEPA	Illinois Environmental Protection Agency
MBI	Macroinvertebrate Biotic Index
MWRDGC	Metropolitan Water Reclamation District of Greater Chicago
NAWQA	National Water-Quality Assessment
PCA	Principal components analysis
PIBI	Potential Index of Biotic Integrity
STECR	Sum of trace-element priority pollutant criteria ratios
TECR	Trace-element criteria ratio
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WQI	Water-Quality Index (of the U.S. Environmental Protection Agency)

Surface-Water-Quality Assessment of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin: Analysis of Relations Between Fish-Community Structure and Environmental Conditions in the Fox, Des Plaines, and Du Page River Basins in Illinois, 1982-84

by Peter M. Ruhl

Abstract

Multivariate analyses of fish-community, water-quality, streambed-sediment-quality, and habitat data collected from 1982 through 1984 in the Fox, Des Plaines, and Du Page River Basins in northeastern Illinois indicate that fish-community structure was strongly related to water-quality gradients commonly associated with differences between agricultural and urban land uses.

Detrended correspondence analysis (DCA) and the Alternate Index of Biotic Integrity (AIBI) tended to group fish communities by river basin. Streams in the predominantly agricultural Fox River Basin tended to have similar DCA scores, the highest AIBI scores, and relatively diverse fish communities that usually included several intolerant species. Streams in the more heavily urbanized Chicago, Little Calumet, Des Plaines, and Du Page River Basins tended to have lower AIBI scores and fish communities dominated by fewer, more tolerant species.

Principal components analysis (PCA) indicated that total recoverable sodium could be used as a proxy for an assemblage of water-quality constituents associated with urban point and nonpoint sources. PCA of streambed-sediment-quality data indicated that total chromium could be used as a proxy for an assemblage of chemical constituents in streambed sediments associated with urban sources.

Correlative (Spearman's rho) and graphical analyses showed that DCA and AIBI scores for nonwadable sites were more strongly related to water quality and streambed-sediment quality than to habitat conditions. DCA and AIBI scores for wadable sites were most strongly related to water quality, were not related to streambed-sediment quality, and were moderately related to habitat variables indicative of stream size. Streams in the Fox River Basin had the smallest concentrations of chemical constituents commonly associated with anthropogenic sources. Streams in the more heavily urbanized Des Plaines and Du Page River Basins had larger concentrations of chemical constituents associated with urban runoff and point-source discharges.

Although fish-community structure was strongly related to the water quality, U.S. Environmental Protection Agency acute and chronic criteria for the protection of freshwater aquatic life were exceeded at few stations. These fish communities may have been responding either to concentrations below the U.S. Environmental Protection Agency criteria or to cumulative or synergistic effects of overall water quality.

Analyses that used DCA to summarize fish-community structure were in close agreement with analyses that used the AIBI. The AIBI is similar to the Index of Biotic Integrity (IBI). The close agreement indicates that ordination methods such as DCA may be useful tools for regional water-quality assessments where IBI-style metrics have not been fully developed. Multivariate methods may also be useful for designing, testing, and validating multimetric indices like the IBI.

INTRODUCTION

In 1986, the U.S. Geological Survey (USGS) began testing and refining concepts and approaches for the National Water-Quality Assessment (NAWQA) program. The goals of the NAWQA program are to (1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources, (2) define long-term trends (or lack of trends) in water quality, and (3) identify, describe, and explain, as possible, the major factors that affect observed conditions and trends in water quality (Hirsch and others, 1988).

Implementation of the surface-water component of the NAWQA program requires the use of biological information to aid in interpretation and to enhance knowledge of changes in stream quality. Although the need to incorporate biological information in regional and national water-quality assessments is generally accepted as being important, consensus is lacking as to the specific kinds of biological information necessary for accurate evaluation of changes in stream quality. Of particular concern is the realization that, although descriptively accurate, biological information may be quantitatively intangible for evaluating changes in water quality.

Many water-quality studies use information about the structure or organization of fish and (or) macroinvertebrate communities at different locations. This information commonly consists of data about the kinds of species that compose the community and their relative abundance. These data commonly are analyzed with the objective of providing a direct assessment of the quality of water resources at each location (Karr, 1991) or with the objective of identifying and describing relations between community structure and environmental conditions such as water quality, streambed-sediment quality, and physical habitat.

Identification and description of relations between community structure and environmental conditions is, in essence, a problem of relating observed patterns in community structure to observed patterns in environmental conditions. If such patterns exist, they should be expressed in the biological and environmental data. The analytical challenge is to identify, summarize, relate, and interpret these patterns.

Many ecologists have used indirect gradient analysis to study patterns between community structure and environmental conditions (Gauch, 1982; Ter Braak, 1986). Indirect gradient analysis is a two-step process. The first step is to summarize patterns in community structure without regard to any knowledge about environmental conditions. The second step is to evaluate relations between patterns in community structure and patterns in environmental conditions. The second step is typically accomplished through graphical means, correlation analysis, and regression analysis (Gauch, 1982; Ter Braak, 1986).

Multivariate analytical techniques of classification and ordination are commonly used to summarize patterns in community structure in the first step of indirect gradient analysis (Gauch, 1982). Multivariate techniques summarize patterns in community structure by describing major patterns of association within a species-by-samples data matrix. A species-by-samples data matrix organizes the data such that each row corresponds to a particular species, each column corresponds to a particular sample, and each item in the matrix contains the number of individuals of a particular species that were captured in a particular sample.

Classification summarizes patterns within this matrix by assigning samples to groups according to the degree to which samples are similar or dissimilar. Ordination summarizes patterns within this matrix by defining a series of axes that express the major gradients in community structure (Gauch, 1982).

Although multivariate techniques for summarizing community structure have been used for a wide variety of ecological investigations (Gauch, 1982), they have not been widely applied in regional water-quality assessments (Leland and others, 1986), and their utility in that context is uncertain. Of particular concern is the realization that results can be an artifact of the procedures and data (Wartenberg and others, 1987; Minchin, 1987; Peet and others, 1988; Fausch and others, 1990).

As part of the upper Illinois River Basin NAWQA pilot study (Mades, 1987), a widely used multivariate ordination technique, detrended correspondence analysis (DCA), was investigated for indirect gradient analysis of relations between community structure and environmental conditions. Of particular interest was how this approach might be applied to the analysis of data collected during regional-scale, spatially oriented water-quality assessments. These assessments would result in regional-scale data sets having (1) biological, chemical, and habitat data for a large number of sites, (2) low temporal resolution (a small number of samples for each site), and (3) a large number of biological (for example, species) and environmental (for example, water quality) variables.

Because the upper Illinois River Basin has been the focus of numerous biological and water-quality investigations, existing data could be assembled to create data sets with applicable characteristics. Steffeck and Striegl (1989) identified 107 sources of information about fish communities and populations in the upper Illinois River Basin. Many of these sources were inventoried to determine (1) where fish-community samples had been collected, (2) how those samples had been collected, (3) whether environmental data on water quality, streambed-sediment quality, or physical habitat also had been collected at those locations, (4) when environmental data were collected, and (5) the methods that were used to collect the environmental data. The inventory focused on data about fish communities and populations that were collected from 1970 through 1986.

The inventory showed that the most comprehensive set of fish-community and environmental data were collected from 1982 through 1984 during basin-wide water-quality surveys of the Fox, Des Plaines, and Du Page River Basins in northeastern Illinois. These surveys were done by the Illinois Environmental Protection Agency (IEPA), in cooperation with Illinois Department of Conservation (IDOC) and the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). For the remainder of this report, these cooperative efforts are referred to as the "intensive basin surveys."

The intensive basin surveys resulted in a comprehensive suite of spatially and temporally compatible biological, chemical, and physical data for many locations. A total of 100 stations were sampled: 86 for fish communities, 88 for water quality, and 81 for streambed-sediment quality. In-stream habitat conditions were characterized for 68 of the stations.

Purpose and Scope

This report presents the results of an indirect gradient analysis of relations between fish-community structure and water quality, streambed-sediment quality, and habitat in the Fox, Des Plaines, and Du Page River Basins in northeastern Illinois. The purpose of the analysis was to (1) identify and describe some of the predominant environmental factors that affect the structure of fish communities within these river basins and (2) provide an example of the use of indirect gradient analysis for regional-scale, spatially oriented water-quality assessments. The scope of the analysis was limited to fish-community, water-quality, streambed-sediment-quality, and habitat data collected during the intensive basin surveys.

Fish-community structure is summarized by use of DCA, a multivariate ordination technique, and the AIBI. Results based on DCA and the AIBI are compared. This report also discusses the use of indirect gradient analysis for regional-scale, spatially oriented water-quality assessments.

Previous Studies

The IEPA and IDOC presented the results of the intensive basin surveys in five reports. The IEPA released separate reports for the Fox River Basin (Illinois Environmental Protection Agency, 1987b), the Des Plaines River Basin (Illinois Environmental Protection Agency, 1988a), and the Du Page River Basin (Illinois Environmental Protection Agency, 1988b). The IDOC released two reports: one for the Fox River Basin (Sallee and Bergmann, 1986), and one for both the Des Plaines and Du Page River Basins (Bertrand, 1984).

Overall water quality for each station was summarized with the U.S. Environmental Protection Agency (USEPA) Water-Quality Index (WQI). The WQI score for a given sample is based on water temperature, pH, and concentrations of dissolved oxygen, total phosphorus, total suspended solids, un-ionized ammonia, and metals (Illinois Environmental Protection Agency, 1988a). The IEPA also evaluated water quality at each sampling station by comparing constituent concentrations to applicable Illinois water-quality standards.

Macroinvertebrate data for each station were summarized with the Macroinvertebrate Biotic Index (MBI), a modification of the Hilsenhoff Biotic Index (Hilsenhoff, 1982). The MBI is calculated by summing water-quality-tolerance values for macroinvertebrate taxa that are collected at a particular station.

Fish-community data for each station were summarized with the Alternate Index of Biotic Integrity (AIBI) (Hite and Bertrand, 1989). The AIBI, a modified version of the Index of Biotic Integrity (IBI) (Karr and others, 1986), is described in greater detail in the methods section of this report. The IDOC reports also summarized fish-community structure with Brillouin's diversity index (H') (Kaesler and Herricks, 1976) and compared the number of species captured at each station (species richness).

Habitat conditions at each station were summarized with the Potential Index of Biotic Integrity (PIBI). The PIBI was designed to provide an indication of the potential for a site to support a well-balanced fish community if habitat conditions, rather than water quality, were the limiting factor. The PIBI was developed by regressing AIBI scores against selected habitat variables (Illinois Environmental Protection Agency, 1988a).

The IEPA reports also described streambed-sediment quality at each station according to a classification scheme for Illinois streambed sediments (Kelly and Hite, 1984). That scheme allows the concentration of each chemical constituent to be classified as either (1) extremely elevated, (2) highly elevated, (3) elevated, (4) slightly elevated, or (5) nonelevated. The IEPA also compared the mean concentrations of each constituent among river basins and areas within river basins.

The three IEPA reports showed that the conditions of streams in the Des Plaines and Du Page River Basins were substantially poorer than conditions in the Fox River Basin. Mean WQI, MBI, and AIBI scores all indicated that water quality, macroinvertebrate communities, and fish communities were more degraded in the Des Plaines and Du Page River Basins than in the Fox River Basin. Streambed sediments in the Des Plaines and Du Page River Basins also had higher concentrations of metals and synthetic organochlorine compounds. Many of the streambed-sediment samples from the Des Plaines and Du Page River Basins were classified as extremely elevated; sediments from the Des Plaines River Basin generally had the highest concentrations among streams in northeastern Illinois (Illinois Environmental Protection Agency, 1988a). The poorest water quality and streambed-sediment quality generally were found in the urbanized areas of all three basins.

Bertrand (1984), who used a qualitative approach to compare H' and AIBI scores to water-quality and habitat conditions, concluded that fish communities in the Des Plaines and Du Page River Basins were probably limited by water quality rather than by habitat. Bertrand also noted that the most degraded fish communities were found in the most heavily urbanized areas.

Sallee and Bergmann (1986), in a more quantitative approach, compared fish-community structure to environmental conditions in the Fox River Basin. They examined correlations (Spearman's rho) between H' and AIBI scores and a set of water-quality, streambed-sediment-quality, habitat, and human-population variables. They concluded that habitat conditions did not explain differences in fish-community structure. Instead, they found a strong relation between fish-community structure and human-population density. Few significant correlations were found between fish-community variables (H' and AIBI) and individual water-quality and streambed-sediment variables. High stream-water values for specific conductance and low concentrations of nitrite plus nitrate nitrogen were associated with degraded fish communities.

Despite the extensive analysis, none of the reports integrates the results from all three basins to provide a comprehensive assessment and comparison of environmental conditions in northeastern Illinois. The most detailed interbasin comparisons contained in these reports are for chemical constituents of streambed sediments (Illinois Environmental Protection Agency, 1988a). In addition, only authors of the IDOC report for the Fox River Basin attempted quantitative identification and definition of relations between fish- and macroinvertebrate-community structure and environmental conditions or land use (Sallee and Bergmann, 1986).

Acknowledgments

I thank William Bertrand, David Day, and Daniel Sallee of the Illinois Department of Conservation and Samuel Dennison of the Metropolitan Water Reclamation District of Greater Chicago for providing unpublished field notes and data sheets. Harry Leland of the U.S. Geological Survey National Research Program provided consultation regarding all aspects of the investigation. I thank Robert Striegl of the U.S. Geological Survey National Research Program and Donald Steffeck of the U.S. Fish and Wildlife Service for initially suggesting that an analysis of available data might prove fruitful.

BASIN DESCRIPTION

The location of the intensive basin survey boundaries within the upper Illinois River Basin are shown in figure 1. The intensive basin surveys were restricted to the Illinois parts of the Fox, Des Plaines, and Du Page River Basins. For the remainder of this report, the term "study area" is used to refer to the area that was sampled during those surveys. A report by Mades (1987) gives a detailed discussion of the geology, climate, and hydrology of the area.

The Fox River (fig. 2) originates in southeastern Wisconsin and flows southward for 180 mi until it empties into the Illinois River near Ottawa, Ill. (Mades, 1987). The Fox River drains 2,658 mi^2, 1,788 of which are in Illinois (Healy, 1979). Approximately 85 percent of the area is either agricultural or forested land; land use in the basin is dominated by row-crop agriculture. The remaining 15 percent of the basin is urbanized (Mades, 1987). The most significant urban areas are in the middle part of the Fox River Basin immediately west of Chicago (fig. 1).

The Des Plaines River (fig. 3) lies to the east of the Fox River (fig. 1). It begins in southeastern Wisconsin and flows south for 130 mi until it joins the Kankakee River to form the Illinois River (Mades, 1987). The Des Plaines River drains 2,111 mi^2, 1,995 of which are in Illinois (Healy, 1979). Land use in the northern part of the Des Plaines River Basin is dominated by row-crop agriculture (Mades, 1987). The middle and southern parts of the basin are dominated by the Chicago metropolitan area. During the early 1980's, approximately 58 percent of the entire population of Illinois resided in the four counties that lie wholly or partly within the basin (Bertrand, 1984). Flow regimes in the Des Plaines River Basin have been extensively altered through urban development and channel modifications. Streamflows are affected by numerous point-source discharges, by channelization, and by stormwater-management structures.

The Chicago and Little Calumet Rivers (fig. 4) are tributaries of the Des Plaines River. They are discussed separately in this report because they drain some of the most heavily urbanized and industrialized areas of the Des Plaines River Basin (fig. 1) and because they have fish communities and water-quality conditions that tend to separate them from the rest of the basin. The Chicago River originates in the northern suburbs of the Chicago metropolitan area and flows southwestward through downtown Chicago to its confluence with the Chicago Sanitary and Ship Canal (fig. 1). Water from Lake Michigan enters the Chicago River from the North Shore Channel and from the Chicago River Lock in downtown Chicago. The Chicago River drains 113 mi^2 before it is affected by flow from Lake Michigan (Healy, 1979). The Little Calumet River originates in northwestern Indiana and flows west past Gary, Ind., into Illinois, where it empties into the Calumet Sag Channel. The Little Calumet River drains 291 mi^2 (Healy, 1979).

The Du Page River Basin (fig. 5) lies between the southern reaches of the Des Plaines and Fox Rivers and drains 376 mi^2 (Healy, 1979). A large part of the Du Page River Basin is in the western suburbs of Chicago, and land use in the northern part of the basin is predominantly urban (fig. 1). Land use in the southern part of the basin is predominantly agricultural (Freeman and others, 1986). Land use throughout the Du Page River Basin has been shifting from agricultural uses to urban uses since the 1940's. This transition has been particularly rapid during the last several decades; during the 1980's, the Du Page River Basin was one of the most rapidly urbanizing regions in Illinois (Illinois Environmental Protection Agency, 1988b). Both the East and West Branches of the Du Page River originate as effluent from wastewater-treatment plants, and most of the streamflow in the main stem during low-flow periods is treated wastewater (Freeman and others, 1986).

DATA SELECTED FOR ANALYSES

Data from the intensive basin surveys were obtained from published reports (Bertrand, 1984; Illinois Environmental Protection Agency, 1987b,

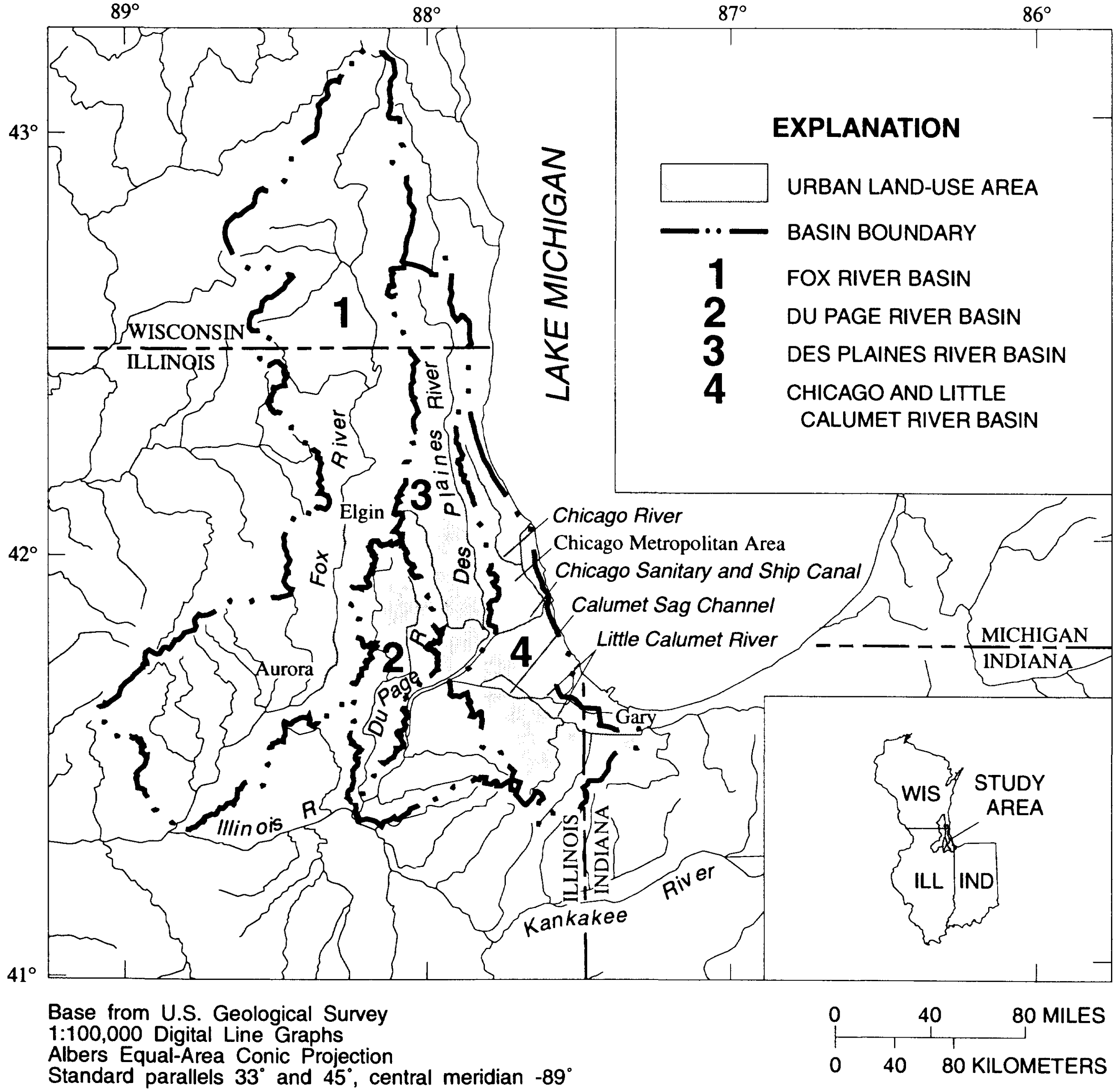


Figure 1. Location of intensive basin survey boundaries within the upper Illinois River Basin.

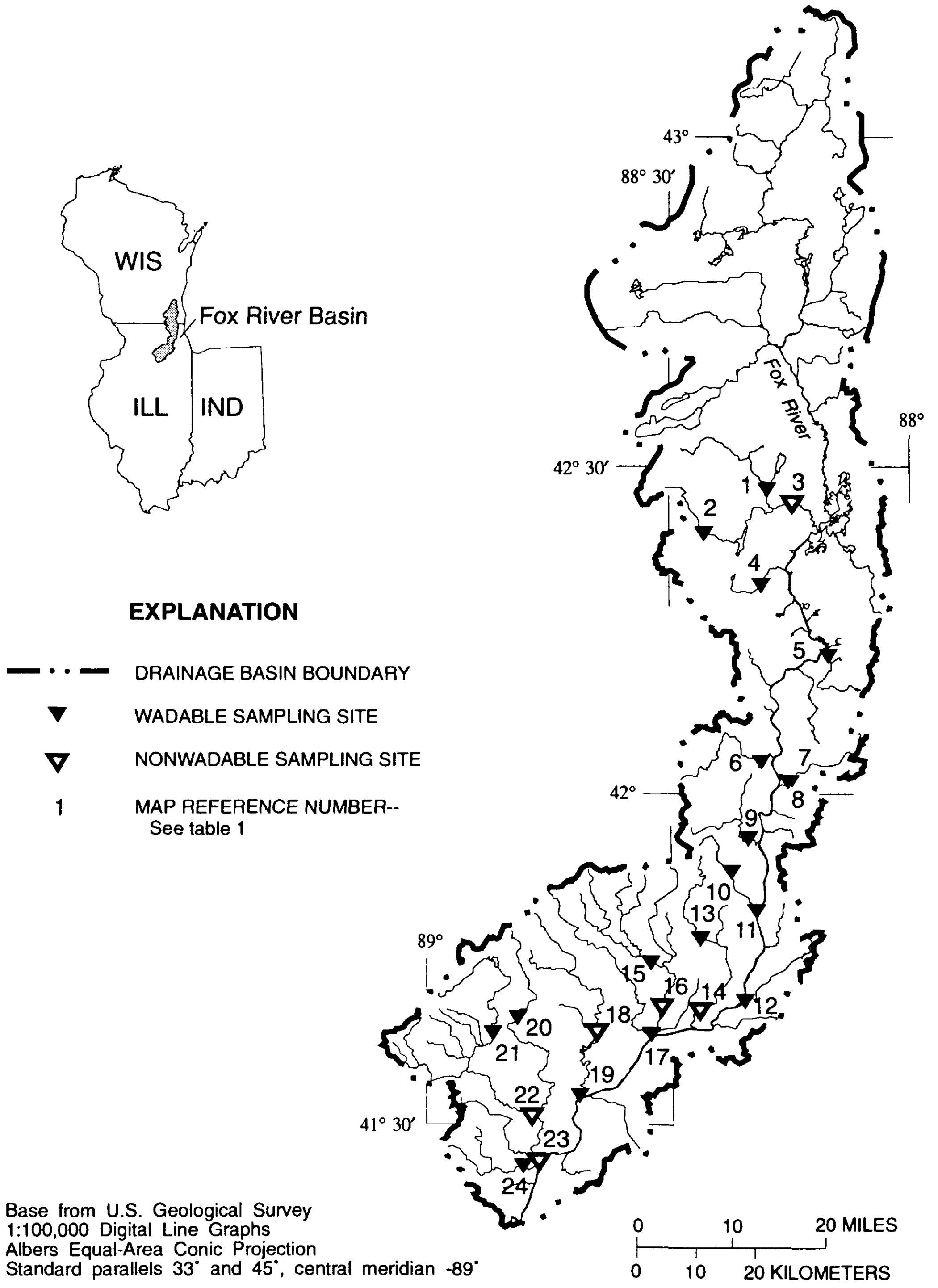
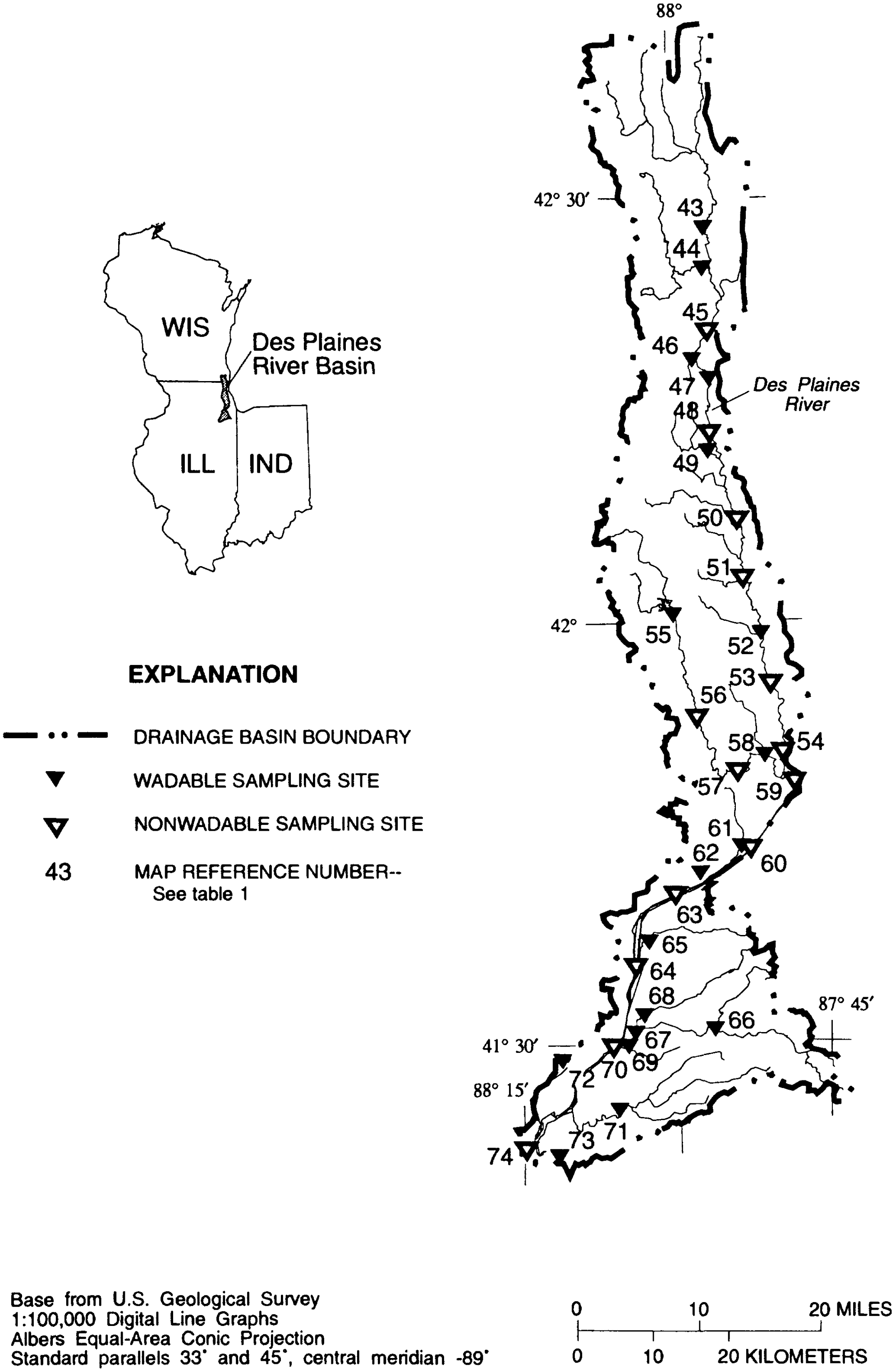
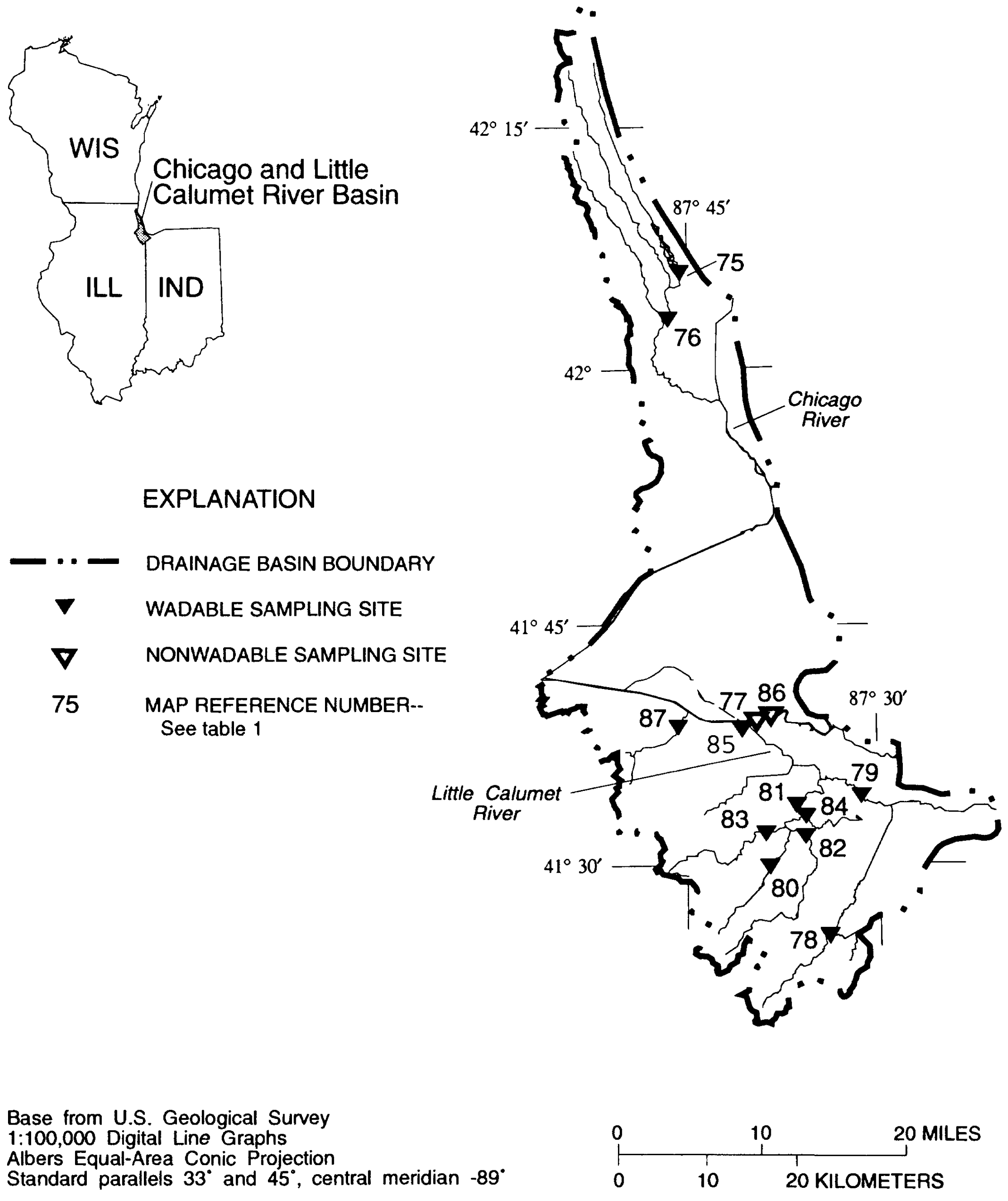


Figure 2. Fox River Basin and the location of intensive basin survey sampling stations.



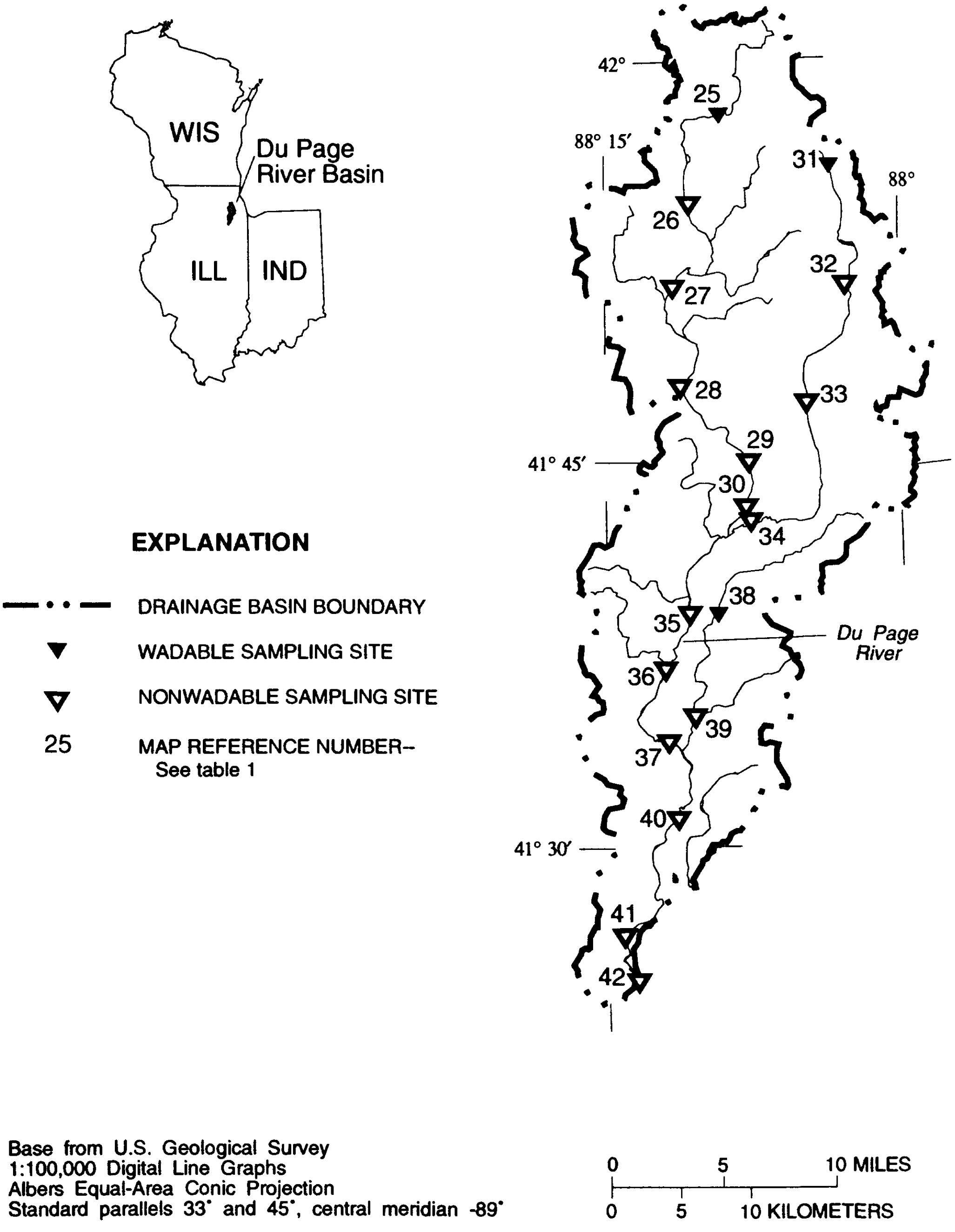
Base from U.S. Geological Survey
1:100,000 Digital Line Graphs
Albers Equal-Area Conic Projection
Standard parallels 33° and 45°, central meridian -89°

Figure 3. Des Plaines River Basin and the location of intensive basin survey sampling stations.



Base from U.S. Geological Survey
1:100,000 Digital Line Graphs
Albers Equal-Area Conic Projection
Standard parallels 33° and 45°, central meridian -89°

Figure 4. Chicago and Little Calumet River Basins and the location of intensive basin survey sampling stations.



Base from U.S. Geological Survey
1:100,000 Digital Line Graphs
Albers Equal-Area Conic Projection
Standard parallels 33° and 45°, central meridian -89°

Figure 5. Du Page River Basin and the location of intensive basin survey sampling stations.

1988a, 1988b; Sallee and Bergmann, 1986), unpublished sources (David Day, Illinois Department of Conservation, written commun., 1991; S.G. Dennison, Metropolitan Water Reclamation District of Greater Chicago, written commun., 1991), and digital data bases. The data were evaluated to determine their suitability for analysis. The evaluation focused on (1) the comparability of fish-community-sampling methods and (2) the temporal compatibility between fish-community and water-quality data.

Fish-Community Data

Data from 85 of 86 intensive basin survey fish-community-sampling stations were selected for analysis (tables 1 and 2). One sample was collected at each of 86 stations; however, data from station HB-42 was rejected because the sample was collected in a unique manner. Data on the number of individuals of each species collected in each sample were obtained from published reports (Bertrand, 1984; Sallee and Bergmann, 1986) and unpublished records of the MWRDGC (S.G. Dennison, written commun., 1991). Detailed information about site-specific sampling methods was obtained from unpublished records of the IDOC (David Day, written commun., 1991) and the MWRDGC (S.G. Dennison, written commun., 1991).

Stations in the Fox River Basin were sampled during August 1982; samples were collected at 23 stations on 16 tributaries. In the Des Plaines River Basin, samples were collected from June through October 1983 at 32 stations. Eighteen of these stations were on tributaries and 14 were on the main stem. The Du Page River Basin was sampled in May 1983; samples were collected from 12 tributary and 6 main-stem stations. The Chicago and Little Calumet River Basin was sampled between June and October 1984.

Inspection of discharge hydrographs for USGS streamflow-gaging stations in the Fox and Des Plaines River Basins showed that fish-community samples were collected during a period of relatively low, stable streamflow. Discharge hydrographs for USGS streamflow-gaging stations in the Du Page River Basin indicate that streamflows increased shortly before samples were collected and discharge was slightly higher than normal, but receding, when fish were collected during early May 1983.

Wadable stations were sampled by means of a direct current backpack electroshocker, a minnow seine, or a combination of the two. When electrical conductance was too high for effective electroshocking, samples were collected by use of seines only (Bertrand, 1984). Sampling reaches at wadable stations ranged from 150 to 500 ft; average length was 340 ft (S.G. Dennison, written commun., 1991; David Day, written commun., 1991). Electroshocking consisted of a single pass through the sampling reach. The reach was seined by use of either a 15-ft by 6-ft bag seine (¼-in. mesh) or a 30-ft by 6-ft bag seine (¼-in. mesh). Samples were also collected by placing a seine in a stationary position and disturbing the substrate immediately upstream (S.G. Dennison, written commun., 1991; David Day, written commun., 1991).

Nonwadable (boat) stations were sampled by use of a 3-phase alternating-current boat-mounted electroshocking unit powered by a 230-volt, 180-cycle, 3,000-watt generator (Bertrand, 1984; Sallee and Bergmann, 1986). Boat electrofishing at stations in the Fox River Basin was supplemented by seining and (or) substrate-disturbance sampling (David Day, written commun., 1991). Sampling reaches at nonwadable sites ranged from approximately 660 ft to approximately 2,600 ft. The average length of nonwadable reaches was approximately 1,770 ft (S.G. Dennison, written commun., 1991; David Day, written commun., 1991).

A total of 11,789 fish were collected during the intensive basin surveys, representing 57 species and 2 hybrids from 11 families (table 2). The family Cyprinidae (minnows) was represented by the largest number of species (22) and 1 hybrid, followed by the family Centrarchidae (sunfishes) with 9 species and 1 hybrid and the family Catostomidae (suckers) with 8 species. Green sunfish (1,729 individuals, 73 stations), bluntnose minnow (1,082 individuals, 58 stations), and common carp (1,146 individuals, 57 stations) were the most abundant and most frequently collected species. White suckers also were common (67 stations), though less abundant (696 individuals).

Fish-community data collected at nonwadable sites were analyzed separately from data collected at wadable sites. This is because nonwadable and wadable sites were sampled by use of different methods (boat electroshocking or backpack electroshocking and minnow seining), and sampling efficiencies differed between methods (Bayley and Austen, 1987; Bayley and others, 1989).

Table 1. Fish-community-sampling stations selected for analysis

[IEPA, Illinois Environmental Protection Agency; mi, miles; --, no data]

An "X" entry in a column indicates that the specified type of data were collected at the sampling station. The superscript ^{d} indicates that habitat data such as substrate composition and the abundance of fish cover are available; otherwise, habitat data are available only for basic information such as mean width, depth, and discharge. Abbreviations used for fish sampling gear are boat, 3-phase alternating-current boat-mounted boom electroshocker; bp, direct-current backpack electroshocker; and s, small-mesh minnow seine.

			Type of data collected				
Map number	IEPA station identifier	Station location	Fish community	Fish-sampling gear	Habitat	Water quality	Streambed-sediment quality
		Fox River Basin					
1	DTKA04	North Branch Nippersink Creek at Hill Road, 0.5 mi southeast of Richmond, Ill.	X	bp+s	X^{d}	X	X
2	DTK_06	Nippersink Creek at Allendale Road, 6.0 mi north of Woodstock, Ill.	X	bp+s	X^{d}	X	X
3	DTK_04	Nippersink Creek at Winn Road, Spring Grove, Ill.	X	boat+s	X^{d}	X	X
4	DTZT02	Boone Creek at Bull Valley Road, 3 mi southwest of McHenry, Ill.	X	bp+s	X^{d}	X	X
5	DTZS01	Flint Creek at Kelsey Road in Lake Barrington, Ill.	X	bp+s	X^{d}	X	X
6	DTZP02	Tyler Creek at Route 31 near Tyler Creek Forest Preserve and I-90 junction, Elgin, Ill.	X	bp	X^{d}	X	X
7	[1]DTG_02	Poplar Creek at U.S. Highway B.R. 20 (Villa Street) in Elgin, Ill.	--	--	--	X	--
8	DTG_03	Poplar Creek at Bluff City Boulevard in Elgin, Ill.	X	bp+s	X^{d}	--	X
9	DTF_02	Ferson Creek at Randall Road, 2.0 mi northwest of St. Charles, Ill.	X	bp+s	X^{d}	X	X
10	DTZL02	Mill Creek at Keslinger Road, 3.5 mi west of Geneva, Ill.	X	bp	X^{d}	X	X
11	DTZL01	Mill Creek at Route 31 at Mooseheart, Ill.	X	bp	X^{d}	X	X
12	DTE_01	Waubansee Creek at Route 25 in Oswego, Ill.	X	bp+s	X^{d}	X	--
13	DTD_03	Blackberry Creek at Bliss Road at the Sugar Creek Forest Preserve, 4.0 mi north of Sugar Grove, Ill.	X	bp+s	X^{d}	X	X
14	DTD_02	Blackberry Creek at Route 47, 2.0 mi north of Yorkville, Ill.	X	boat+s	X^{d}	X	X
15	DTC_03	Big Rock Creek at Granart Road, 1.5 mi south of Big Rock, Ill.	X	bp	X^{d}	X	X
16	DTC_06	Big Rock Creek, 1.5 mi north of Route 34, 1.5 mi north of Plano, Ill.	X	boat+s	X^{d}	X	X
17	DTCA01	Little Rock Creek at county road bridge, 1.5 mi south of Plano, Ill.	X	bp+s	X^{d}	X	X
18	DTB_02	Somonauk Creek at Route 34 near Sannauk Forest Preserve, 1.5 mi east of Somonauk, Ill.	X	boat+s	X^{d}	X	X
19	DTB_01	Somonauk Creek at east-west township road bridge, 1.0 mi north of Sheridan, Ill.	X	bp+s	X^{d}	X	X
20	DTAB01	Little Indian Creek at Suydam Road, 3.3 mi north-northwest of Leland, Ill.	X	bp+s	X^{d}	X	X
21	DTA_06	Indian Creek at Svendsen Road, 2.6 mi southeast of Rollo, Ill.	X	bp+s	X^{d}	X	X
22	DTA_05	Indian Creek at Harding Road, 3.2 mi east of Harding, Ill.	X	boat+s	X^{d}	X	X
23	DTA_01	Indian Creek at Somonauk Road, 0.5 mi north of Wedron, Ill.	X	boat+s	X^{d}	X	X
24	DTZB02	Buck Creek at north-south county road bridge, 1.5 mi west of Wedron, Ill.	X	bp	X^{d}	X	X

Table 1. Fish-community-sampling stations selected for analysis—Continued

Map number	IEPA station identifier	Station location	Type of data collected				
			Fish community	Fish-sampling gear	Habitat	Water quality	Streambed-sediment quality
		Du Page River Basin					
25	GBK_11	West Branch Du Page River at Jefferson Street bridge, Hanover Park, Ill.	X	bp+s	X[d]	X	X
26	GBK_09	West Branch Du Page River at Route 64, 2 mi north-northeast of West Chicago, Ill.	X	boat	X[d]	X	X
27	GBK_07	West Branch Du Page River at Garys Mill Road, West Chicago, Ill.	X	boat	X[d]	X	X
28	GBK_12	West Branch Du Page River at McDowell Forest Preserve Road, northwest of Naperville, Ill.	X	boat	X	X	X
29	GBK_01	West Branch Du Page River at Hobson Road, Naperville, Ill.	X	boat	X	X	X
30	GBK_02	West Branch Du Page River at Washington Street, south of Naperville, Ill.	X	boat	X	X	X
31	GBL_11	East Branch Du Page River at Army Trail Road, south of Bloomingdale, Ill.	X	bp+s	X[d]	X	X
32	GBL_08	East Branch Du Page River at Route 38, Glen Ellyn, Ill.	X	boat	X[d]	X	X
33	GBL_05	East Branch Du Page River at Maple Avenue, Lisle, Ill.	X	boat	X[d]	X	X
34	GBL_02	East Branch Du Page River at Washington Street, south of Naperville, Ill.	X	boat	X	X	X
35	GB__12	Du Page River at 127th Street, northeast of Plainfield, Ill.	X	boat	X	X	X
36	GB__09	Du Page River at Route 59, Plainfield, Ill.	X	boat	X	X	X
37	GB__13	Du Page River at Route 59, 2.5 mi south of Plainfield, Ill.	X	boat	X	X	X
38	GBE_02	Lily Cache Creek at 127th Street, northeast of Plainfield, Ill.	X	bp	X[d]	X	X
39	GBE_01	Lily Cache Creek at Route 30, 1 mi southeast of Plainfield, Ill.	X	boat	X[d]	X	X
40	GB__11	Du Page River at Route 52, Shorewood, Ill.	X	boat	X	X	X
41	GB__03	Du Page River at county road bridge, 1.5 mi north-northwest of Channahon, Ill.	X	boat	X	X	X
42	GB__01	Du Page River at Old Route 6, southwest edge of Channahon, Ill.	X	boat	X	X	X
		Des Plaines River Basin					
43	G___34	Des Plaines River near Russell, Ill.	X	s	X[d]	X	X
44	GW__02	Mill Creek at Wadsworth, Ill.	X	bp+s	X[d]	X	X
45	G___07	Des Plaines River at Gurnee, Ill.	X	boat	X[d]	X	X
46	GV__01	Bull Creek at Libertyville, Ill.	X	s	X[d]	X	X
47	G___26	Des Plaines River at Libertyville, Ill.	X	s	X[d]	X	--
48	G___35	Des Plaines River at Half Day, Ill.	X	boat	--	--	--
49	GU__02	Indian Creek at Half Day, Ill.	X	s	X[d]	X	X
50	G___36	Des Plaines River at Wheeling, Ill.	X	boat	--	X	--
51	G___28	Des Plaines River at Des Plaines, Ill.	X	boat	--	X	X

Table 1. Fish-community-sampling stations selected for analysis—Continued

			Type of data collected				
Map number	IEPA station identifier	Station location	Fish community	Fish-sampling gear	Habitat	Water quality	Streambed-sediment quality
		Des Plaines River Basin—Continued					
52	GO__01	Willow Creek at Park Ridge, Ill.	X	s	--	X	X
53	G___30	Des Plaines River at Franklin Park, Ill.	X	boat	--	--	X
54	G___32	Des Plaines River at Riverside, Ill.	X	boat	--	X	X
55	GL__10	Salt Creek at Elk Grove, Ill.	X	s	X^d	X	--
56	GL__03	Salt Creek at Villa Park, Ill.	X	boat	--	X	--
57	GL__09	Salt Creek at Western Springs, Ill.	X	boat	--	X	X
58	GLA_01	Addison Creek at Broadview, Ill.	X	s	X^d	X	X
59	G___33	Des Plaines River at Lyons, Ill.	X	boat	--	X	--
60	G___18	Des Plaines River at Willow Springs, Ill.	X	boat	--	X	--
61	GK__03	Flag Creek at Willow Springs, Ill.	X	s	X^d	X	X
62	GJ__01	Sawmill Creek at Darien, Ill.	X	s	X^d	X	X
63	G___03	Des Plaines River at Lemont, Ill.	X	boat	--	X	--
64	G___11	Des Plaines River at Lockport, Ill.	X	boat	--	X	--
65	GHE_01	Long Run at Lemont, Ill.	X	s	X^d	X	--
66	GG__06	Hickory Creek near New Lenox, Ill.	X	s	--	X	X
67	GG__02	Hickory Creek at Joliet, Ill.	X	bp+s	X^d	X	X
68	GGA_02	Spring Creek at Joliet, Ill.	X	bp	X^d	X	--
69	GF__01	Sugar Run at Nowell, Ill.	X	bp	X^d	X	X
70	G___12	Des Plaines River at Joliet, Ill.	X	boat	--	X	--
71	GC__02	Jackson Creek near Elwood, Ill.	X	s	X^d	X	X
72	GBAA01	Rock Run near Troy, Ill.	X	bp	--	X	X
73	GA__01	Grant Creek at Channahon, Ill.	X	bp	X^d	X	--
74	G___24	Des Plaines River at Joliet, Ill.	X	boat	--	X	X
		Chicago and Little Calumet River Basins					
75	HCCD09	Skokie River at Northfield, Ill.	X	bp	X^d	X	X
76	HCCC04	Middle Fork North Branch Chicago River at Glenview, Ill.	X	bp+s	X^d	X	X
77	H___04	Little Calumet River at Calumet Park, Ill.	X	boat	--	--	X
78	HBE_02	Plum Creek at Crete, Ill.	X	bp+s	X^d	X	X
[2]79	HB__42	Little Calumet River at Lansing, Ill.	--	--	--	X	X
80	HBD_05	Thorn Creek at Chicago Heights, Ill.	X	bp+s	X^d	X	X
81	HBD_04	Thorn Creek at Thornton, Ill.	X	bp+s	--	X	X
82	HBDC02	Deer Creek at Glenwood, Ill.	X	bp+s	X^d	X	X
83	HBDB03	Butterfield Creek at Homewood, Ill.	X	bp+s	X^d	X	X
84	HBDA01	North Creek at Glenwood, Ill.	X	bp	X^d	X	X
85	HBA_01	Midlothian Creek at Blue Island, Ill.	X	bp	X^d	X	X
86	HB__01	Little Calumet River at Blue Island, Ill.	X	boat	--	X	X
87	HF__01	Tinley Creek at Crestwood, Ill.	X	bp	X^d	X	X

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[1] Water-quality data used for fish-community sample collected at DTG_03.

[2] Station HB_42 (map number 79) was not used in the analysis because an unusual method was used to capture fish at this station.

Table 2. Fish species collected in the upper Illinois River Basin at Illinois Environmental Protection Agency stations selected for analysis

[DCA, Detrended correspondence analyses. Common and scientific names conform with Robins and others (1991). The column titled "DCA abbreviation" contains the abbreviations used in the DCA species ordination diagrams]

Family Scientific name	Common name	DCA abbreviation	Number of stations (occurrence)	Number of individuals (abundance)
Clupeidae (herrings)				
Dorosoma cepedianum	Gizzard shad	GIZRDSHD	16	111
Cyprinidae (carps and minnows)				
Campostoma spp.	Stoneroller	STONERLR	33	607
Carassius auratus	Goldfish	GOLDFISH	16	71
Cyprinella lutrensis	Red shiner	REDSHIN	2	2
Cyprinella spiloptera	Spotfin shiner	SPTFNSH	31	779
Cyprinus carpio	Common carp	CARP	57	1,146
Cyprinus carpio x Carassius auratus	Carp x goldfish hybrid	CRP-GLD	18	55
Luxilus chrysocephalus	Striped shiner	STRPSHI	5	207
Luxilus cornutus	Common shiner	CMNSHIN	30	467
Lythrurus umbratilis	Redfin shiner	RDFINSH	11	214
Nocomis biguttatus	Hornyhead chub	HRNYHDC	23	242
Notemogonus crysoleucas	Golden shiner	GLDSHIN	27	134
Notropis atherinoides	Emerald shiner	EMRLDSH	4	33
Notropis dorsalis	Bigmouth shiner	BGMTHSH	27	306
Notropis hudsonius	Spottail shiner	SPTTLSH	2	2
Notropis rubellus	Rosyface shiner	RSYFCSH	9	84
Notropis stramineus	Sand shiner	SNDSHIN	28	402
Phenacobius mirabilis	Suckermouth minnow	SKRMMIN	7	14
Phoxinus erythrogaster	Southern redbelly dace	SRDBDA	2	88
Pimephales notatus	Bluntnose minnow	BLNTNSM	58	1,082
Pimephales promelas	Fathead minnow	FTHDMIN	33	267
Pimephales vigilax	Bullhead minnow	BULLMIN	1	1
Rhinichthys atratulus	Blacknose dace	BLKNSDA	5	35
Semotilus atromaculatus	Creek chub	CRKCHUB	55	572
Catostomidae (suckers)				
Carpiodes carpio	River carpsucker	RVRCRPS	1	1
Carpiodes cyprinus	Quillback	QUILBACK	16	103
Carpiodes velifer	Highfin carpsucker	HIFCRPS	2	2
Catostomus commersoni	White sucker	WHTSUCK	67	696
Hypentelium nigricans	Northern hog sucker	NHOGSU	20	124
Moxostoma duquesnei	Black redhorse	BLKRDHO	4	40
Moxostoma erythrurum	Golden redhorse	GLDREDH	15	141
Moxostoma macrolepidotum	Shorthead redhorse	SHRTHDR	13	41
Ictaluridae (bullhead catfishes)				
Ameiurus melas	Black bullhead	BLKBULL	28	772
Ameiurus natalis	Yellow bullhead	YLOBULL	11	18
Ictalurus punctatus	Channel catfish	CHNLCAT	7	49
Noturus exilis	Slender madtom	SLNDRMA	1	6
Noturus flavus	Stonecat	STONECAT	8	25
Noturus gyrinus	Tadpole madtom	TDPLMAD	3	5
Esocidae (pikes)				
Esox americanus vermiculatus	Grass pickerel	GRSPICK	4	4
Esox lucius	Northern pike	NPIKE	1	3
Umbridae (mudminnows)				
Umbra limi	Central mudminnow	CNTMUDM	14	33

Table 2. Fish species collected in the upper Illinois River Basin at Illinois Environmental Protection Agency stations selected for analysis—Continued

Family Scientific name	Common name	DCA abbreviation	Number of stations (occurrence)	Number of individuals (abundance)
Cyprinodontidae (killifishes)				
Fundulus notatus	Blackstripe topminnow	BLKSTRIP	5	13
Atherinidae (silversides)				
Labidesthes sicculus	Brook silverside	BRKSILV	5	23
Cottidae (sculpins)				
Cottus bairdi	Mottled sculpin	MTLDSCUL	1	20
Centrarchidae (sunfishes)				
Ambloplites rupestris	Rock bass	ROCKBAS	10	36
Lepomis cyanellus	Green sunfish	GRNSUNF	73	1,729
Lepomis gibbosus	Pumpkinseed	PUMPKINS	11	25
Lepomis humilis	Orangespotted sunfish	RNGSPOTT	2	8
Lepomis hybrid	Hybrid sunfish	HYBSUNF	13	103
Lepomis macrochirus	Bluegill	BLUEGILL	49	218
Micropterus dolomieu	Smallmouth bass	SMLMBAS	15	62
Micropterus salmoides	Largemouth bass	LRGMTHB	40	168
Pomoxis annularis	White crappie	WHTCRAP	3	5
Pomoxis nigromaculatus	Black crappie	BLKCRAP	29	86
Percidae (perches)				
Etheostoma flabellare	Fantail darter	FNTLDAR	9	169
Etheostoma nigrum	Johnny darter	JONYDAR	12	112
Etheostoma spectabile	Orangethroat darter	RNGTHROA	2	11
Perca flavescens	Yellow perch	YLOPERC	5	8
Percina maculata	Blackside darter	BLKSIDA	3	9

Data Set 1–Nonwadable Sites

Data set 1 consists of all fish-community data collected at nonwadable sites by use of a boat-mounted electroshocker (table 3). Data collected through supplemental seining at these sites were not included because seining was done only at stations in the Fox River Basin (David Day, written commun., 1991). Table 2 includes 793 fish collected with seines at boat electrofishing sites; table 3 does not.

Data Set 2–Wadable Sites

Data set 2 consists of fish-community data that were collected at wadable sites by use of a backpack electroshocker, a minnow seine, or both (table 3). These data were combined in one data set because the

Table 3. Characteristics of selected fish-community data sets for the Fox, Des Plaines, and Du Page River Basins
[References to sampling methods are as follows: "boat" means that samples were collected with a boat-mounted electroshocker; "bps" means that samples were collected with a backpack electroshocker, minnow seine, or both. See text for more detailed description of these methods]

Characteristic	Data set 1 Nonwadable sites	Data set 2 Wadable sites
Sampling method	boat	bps
Number of stations		
Total	37	48
Fox River Basin	6	17
Des Plaines River Basin	14	18
Du Page River Basin	15	3
Chicago/Little Calumet River Basin	2	10
Number of species	45	51
Number of hybrids	2	2
Number of fish	4,851	6,145

largest difference in sampling strategy and methods was addressed by separating the data collected with a boat-mounted electroshocker from data collected with backpack electroshockers and seines. Additionally, the sampling protocol for wadable streams called for the combined use of both backpack electroshocking and seining, and this protocol was altered only when conditions at a particular site warranted alteration. If electrical conductance was judged to be too great for effective electroshocking, sampling was done exclusively by seining. Similarly, seining was not used where the presence of snags and adverse substrate conditions would have rendered it ineffective.

Water-Quality Data

The water-quality data set selected for analysis includes 83 samples, 1 each for 83 of the 85 fish-community-sampling stations (table 1). All of the samples were collected either in conjunction with, or shortly before, fish-community samples. Of the 83 samples, 77 were collected on the same day that the fish community was sampled and 6 were collected before the fish community was sampled. Five of these six samples were collected within 14 days of the fish-community sampling. In one case, the water-quality sample was collected 29 days before the fish community was sampled. Water-quality samples collected before the fish-community samples were selected only if a comparison of water temperature and (or) discharge indicated that hydrologic conditions were similar.

Water-quality samples were collected by means of the equal transit rate, equal width increment, multi-vertical method (Illinois Environmental Protection Agency, 1984) and were processed and analyzed according to standard IEPA protocols (Illinois Environmental Protection Agency, 1987a). Data for samples collected at IEPA ambient water-quality-monitoring-network stations were obtained from the USGS WATSTORE data base. Data collected at stations that were not part of the IEPA ambient water-quality-monitoring network were obtained from the USEPA STORET data base. Values reported as zero were edited; the data set indicated that these values were less than the highest detection limit recorded in the WATSTORE data base for samples collected and analyzed by the IEPA during 1982-84. Values of constituents or properties that could reasonably be expected to be zero, such as water temperature, were not edited.

The data retrieved from STORET and WATSTORE included 66 water-quality constituents and properties. Constituents measured at fewer than 10 of the 83 stations were eliminated from further consideration because sample size was insufficient for statistical comparisons. The resulting data set consisted of data for 61 constituents or properties. These included 6 major ions, hardness as calcium carbonate, dissolved and total phosphorus, 3 forms of nitrogen, and 18 trace elements. Samples for most of the major ions and trace elements were analyzed for dissolved and total recoverable fractions (table 4). Analyses for the total recoverable fraction were done on whole water samples digested with hot hydrochloric acid (Illinois Environmental Protection Agency, 1987a). The data set also included water temperature; turbidity; dissolved, total suspended, and total volatile solids; dissolved oxygen; chemical oxygen demand; pH; total cyanide; specific conductance; and total phenols.

The retrieved data set included 11 USEPA priority pollutants (U.S. Environmental Protection Agency, 1986). Of these, 10 are trace elements and the other is total cyanide. The data for many of the trace-element priority pollutants are heavily censored; that is, many values are less than the analytical detection limit. Heavily censored data provide less information about spatial variability, and hence about gradients, in water quality than data that are not censored. The USEPA priority pollutants for which the largest proportion of censored data are reported for the total recoverable fraction are lead (100 percent of the samples), beryllium (99 percent), silver (95 percent), cadmium (93 percent), and mercury (83 percent). Data for zinc (70 percent), chromium (59 percent), cyanide (57 percent), and copper (52 percent) are moderately censored. Data for nickel (33 percent) and arsenic (6 percent) are the least censored (table 4).

Additional water-quality variables were added to the data set by calculating (1) the concentration of un-ionized ammonia, (2) the ratio of un-ionized ammonia to the USEPA acute criterion for the protection of freshwater aquatic life, (3) the ratio of total nitrogen to total phosphorus (N/P), (4) the ratio of total nitrate to total ammonia (NO_3/NH_4), (5) the ratio of the total recoverable fraction of each trace-element

Table 4. Water-quality and streambed-sediment-quality constituents and properties in the upper Illinois River Basin selected for analysis

[--, not applicable]

The superscript ^{P} in the first column designates constituents that are U.S. Environmental Protection Agency priority pollutants. The column titled "used for PCA?" indicates whether the variable was included in the data sets used for principal components analysis (PCA). The column titled "result of PCA" indicates how a variable was treated for further analysis on the basis of the results of PCA: "indeterminant" means that the variable moderately or heavily loaded on more than one principal component or was lightly loaded on all principal components; "proxy=..." indicates the proxy variable used to represent that variable in relational analyses with fish-community structure; "selected as proxy" indicates that the variable was selected as a proxy for other variables. The column titled "used for relational analyses" indicates whether a variable was used for relational analyses with fish-community structure.

Constituent, property, or characteristic	Number of samples	Percent less than detection limit	Used for PCA?	Result of PCA	Used for relational analyses
Water-quality constituents and properties:					
Specific conductance	82	0	Yes	Indeterminant	Yes
pH	83	0	No	--	No
Temperature, water	83	0	No	--	Yes
Turbidity, NTU	82	0	Yes	Proxy=total suspended solids	No
Oxygen, dissolved	82	0	No	--	Yes
Chemical oxygen demand	83	0	Yes	Indeterminant	Yes
Hardness, as calcium carbonate	81	0	Yes	Selected as proxy	Yes
Calcium, total recoverable	83	0	Yes	Proxy=hardness	No
Calcium, dissolved	81	0	Yes	Proxy=hardness	No
Magnesium, total recoverable	83	0	Yes	Proxy=hardness	No
Magnesium, dissolved	81	0	Yes	Proxy=hardness	No
Sodium, total recoverable	83	0	Yes	Selected as proxy	Yes
Sodium, dissolved	81	0	Yes	Proxy=total sodium	No
Potassium, total recoverable	83	0	Yes	Proxy=total sodium	No
Potassium, dissolved	81	0	Yes	Proxy=total sodium	No
Sulfate, dissolved	83	0	Yes	Indeterminant	No
Fluoride, total	79	0	Yes	Proxy=total sodium	No
Dissolved solids	79	0	Yes	Indeterminant	No
Suspended solids, total	83	0	Yes	Selected as proxy	Yes
Suspended solids, volatile	83	0	Yes	Proxy=total suspended solids	No
Nitrite plus nitrate nitrogen, total	83	0	Yes	Indeterminant	Yes
Nitrogen, ammonia, total	83	0	Yes	Indeterminant	Yes
Nitrogen, total kjeldahl	80	0	Yes	Indeterminant	No
Phosphorus, total	82	0	Yes	Proxy=total sodium	No
Phosphorus, dissolved	82	1	Yes	Proxy=total sodium	No
Aluminum, total recoverable	16	0	No	--	Yes
Aluminum, dissolved	15	27	No	--	No
^{P} Arsenic, total	77	6	Yes	Indeterminant	Yes
Barium, total recoverable	83	0	Yes	Selected as proxy	Yes
Barium, dissolved	81	0	Yes	Proxy=total barium	No
^{P} Beryllium, total recoverable	83	99	No	--	Yes
^{P} Beryllium, dissolved	81	98	No	--	No
Boron, total recoverable	83	0	Yes	Proxy=total sodium	No
Boron, dissolved	81	0	Yes	Proxy=total sodium	No
^{P} Cadmium, total recoverable	83	93	No	--	Yes

Table 4. Water-quality and streambed-sediment-quality constituents and properties in the upper Illinois River Basin selected for analysis—Continued

Constituent, property, or characteristic	Number of samples	Percent less than detection limit	Used for PCA?	Result of PCA	Used for relational analyses
Water-quality constituents and properties:—Continued					
[p] Cadmium, dissolved	80	91	No	--	No
[p] Chromium, total recoverable	83	59	No	--	Yes
[p] Chromium, dissolved	81	78	No	--	No
Cobalt, total recoverable	83	93	No	--	Yes
Cobalt, dissolved	81	94	No	--	No
[p] Copper, total recoverable	83	52	Yes	Indeterminant	Yes
[p] Copper, dissolved	81	78	No	--	No
Iron, total recoverable	83	0	Yes	Proxy=total suspended solids	No
Iron, dissolved	81	14	No	--	No
[p] Lead, total recoverable	83	100	No	--	No
[p] Lead, dissolved	81	100	No	--	No
Manganese, total recoverable	83	0	Yes	Selected as proxy	Yes
Manganese, dissolved	81	0	Yes	Proxy=total manganese	No
[p] Mercury, total recoverable	80	83	No	--	Yes
[p] Nickel, total recoverable	83	33	Yes	Selected as proxy	Yes
[p] Nickel, dissolved	81	43	Yes	Proxy=total nickel	No
[p] Silver, total recoverable	83	95	No	--	Yes
[p] Silver, dissolved	81	94	No	--	No
Strontium, total recoverable	83	0	Yes	Proxy=total sodium	No
Strontium, dissolved	81	0	Yes	Proxy=total sodium	No
Vanadium, total	83	89	No	--	Yes
Vanadium, dissolved	81	98	No	--	No
[p] Zinc, total recoverable	83	70	No	--	Yes
[p] Zinc, dissolved	81	75	No	--	No
[p] Cyanide, total	82	57	Yes	Indeterminant	Yes
Phenols, total	35	68	No	--	Yes
Total number of variables used			36		25
Calculated water-quality constituents and properties:					
Total nitrogen to total phosphorus ratio	78	0	No	--	Yes
Total nitrate to total ammonia ratio	81	0	No	--	Yes
Un-ionized ammonia	81	0	No	--	Yes
Un-ionized ammonia criteria ratio	81	0	No	--	Yes
Total arsenic criteria ratio	76	6	No	--	Yes
Total recoverable beryllium criteria ratio	81	99	No	--	No
Total recoverable cadmium criteria ratio	80	94	No	--	No
Total recoverable chromium criteria ratio	79	59	No	--	Yes
Total recoverable copper criteria ratio	80	51	No	--	Yes
Total recoverable nickel criteria ratio	79	34	No	--	Yes
Total recoverable silver criteria ratio	81	96	No	--	No
Total recoverable zinc criteria ratio	81	69	No	--	Yes
Total recoverable mercury criteria ratio	79	82	No	--	No
Sum of trace element criteria ratios	81	2	No	--	Yes
Total number of variables used			0		10

Table 4. Water-quality and streambed-sediment-quality constituents and properties in the upper Illinois River Basin selected for analysis—Continued

Constituent, property, or characteristic	Number of samples	Percent less than detection limit	Used for PCA?	Result of PCA	Used for relational analyses
Streambed-sediment constituents and properties:					
Chemical oxygen demand	80	0	Yes	Selected as proxy	Yes
Solids, volatile	81	0	Yes	Proxy=chemical oxygen demand	No
Nitrogen, total kjeldahl	81	0	Yes	Proxy=chemical oxygen demand	No
Phosphorus, total	81	0	Yes	Indeterminant	No
Arsenic, total	81	2	Yes	Selected as proxy	Yes
Cadmium, total	81	36	Yes	Proxy=total chromium	No
Chromium, total	81	0	Yes	Selected as proxy	Yes
Copper, total	81	0	Yes	Proxy=total chromium	No
Iron, total	81	0	Yes	--	No
Lead, total	81	0	Yes	Proxy=total chromium	No
Manganese, total	81	0	Yes	Proxy=total arsenic	No
Mercury, total	81	0	Yes	Proxy=total chromium	No
Zinc, total	81	0	Yes	Proxy=total chromium	No
PCB's, total	81	41	Yes	Proxy=total chromium	No
Chlordane	81	46	Yes	Proxy=total chromium	No
DDT, total	81	52	Yes	Proxy=total chromium	No
Dieldrin	82	25	Yes	Proxy=total chromium	No
Heptachlor epoxide	81	81	No	--	Yes
Total number of variables used			17		4

priority pollutant to its corresponding USEPA acute criterion for the protection of freshwater aquatic life (trace-element criteria ratio, or TECR), and (6) the sum of the trace-element priority pollutant criteria ratios (STECR).

The concentration of un-ionized ammonia was calculated as a function of pH, water temperature, and the concentration of total ammonia (Illinois Pollution Control Board, 1988). The ratio of un-ionized ammonia to the USEPA acute criterion was calculated to provide an index that takes into account the effect that pH and water temperature have on the toxicity of un-ionized ammonia. The USEPA criterion reflect this relation by making the un-ionized ammonia criterion a function of pH and water temperature (U.S. Environmental Protection Agency, 1986). A value greater than 1 indicates that the USEPA acute criterion was exceeded. The ratios can also be used for nonparametric correlations with other variables.

The N/P and NO_3/NH_4 ratios were calculated because they can help distinguish gradients in water quality that are related to differences between agricultural and urban land uses. Both of these ratios are larger in agricultural areas of the upper Illinois River Basin than in urban areas (Blanchard and Schmidt, in press).

The ratio of the total recoverable fraction of each trace element to its USEPA acute criterion was calculated for two reasons. First, the toxicity of cadmium, chromium, copper, nickel, and zinc are related to hardness (as milligrams per calcium carbonate). The USEPA criteria reflect this by expressing the criteria for these constituents as a function of hardness (U.S. Environmental Protection Agency, 1986). The TECR is an index of the possible toxicity of these constituents that takes hardness into account. Second, the STECR can be used as an index of possible synergistic effects of the trace-element priority pollutants. An index that is calculated as the sum of the concentrations of the individual constituents would not be appropriate because the sum can be inflated by a large concentration of a low-toxicity element. TECR normalizes the concentrations of individual constituents according to a reasonable estimate of their potential to contribute to the overall toxicity of the sample.

The 75 water-quality constituents and properties in the data set used for the analyses are listed in table 4. The number of samples that contained a constituent or property and the percentage of these samples in which the concentration was less than the detection limit can be found in table 4.

Streambed-Sediment-Quality Data

The streambed-sediment-quality data set includes 1 sample from each of 72 intensive basin survey sampling stations (table 1). Samples were collected and processed by use of acetone-washed stainless-steel equipment. Sediments were collected from the upper surface of the streambed, and the fine fraction (less than 62 micrometers) was analyzed for 25 constituents: percent volatile solids (by weight), chemical oxygen demand, total kjeldahl nitrogen, total phosphorus, 9 trace elements, and 12 organochlorine compounds (Illinois Environmental Protection Agency, 1987b, 1988a, 1988b). Trace-element analyses were done after a powdered aliquot was digested in hot (85°C) nitric and hydrochloric acid (Illinois Environmental Protection Agency, 1987a).

Streambed-sediment-quality data were obtained from IEPA reports (Illinois Environmental Protection Agency, 1987b, 1988a, 1988b). Seven organochlorine compounds not detected in any of the samples were eliminated from further consideration. The 18 constituents that were retained for statistical analyses are listed in table 4.

Habitat Data

IEPA investigators measured, estimated, or observed as many as 23 in-stream habitat characteristics at each of 66 fish-community-sampling stations (tables 1 and 5).

At 56 stations, IEPA investigators collected streambed-substrate data using a method modified from Gorman and Karr (1978). The IEPA investigators established 11 evenly spaced transects within each fish-community-sampling reach. Depth, velocity, and substrate composition were recorded at evenly spaced points along each transect. At many of the stations, however, less than 11 transects were sampled because of human-resource constraints and nonwadable depths. Consequently, the number of transects that were sampled varied from 1 to 11; the median number of transects was 5. The interval between the sampling points along each transect was based on mean stream width and ranged from 1 ft for streams less than 10 ft wide to 10 ft for streams greater than 100 ft wide (Illinois Environmental Protection Agency, 1987b, 1988a, 1988b).

The predominant substrate at each sampling point was classified and recorded according to 11 categories. Of these, nine concern substrate particle size. The remaining two concern the presence of bedrock and the presence of vegetative detritus (table 5). Point observations were summarized by calculating the percentage of the total number of observations recorded in each category. Percentage of the stream reach characterized by submerged vegetation, submerged logs, riffle habitat, pool habitat, in-stream cover for fishes, or shade at noon also was estimated. Discharge was calculated from the depth, width, and velocity measurements along one transect.

Habitat data for stations in the Fox River Basin are complete, but habitat data for many of the stations in the Du Page and Des Plaines River Basins are missing or incomplete. Streambed-substrate data were not collected at 10 of the 18 stations in the Du Page River Basin. No habitat data were collected at 16 of the 32 stations in the Des Plaines River Basin and 4 of the 13 stations in the Chicago/Little Calumet River Basin.

More habitat data are incomplete or missing for nonwadable sites than for wadable sites. A complete habitat data set is available for only 12 of the 37 nonwadable stations. No habitat data were collected at 15 of the 37 nonwadable stations. Habitat data for 10 of the nonwadable stations are restricted to stream order, average width, average depth, average flow velocity, discharge, and percentage of cover. In contrast, habitat data are missing for only 4 of the 48 wadable stations.

METHODS OF STUDY

The analytical approach that was used consisted of three interrelated elements: (1) quantitative summarization and description of major patterns in fish-community structure, (2) reduction of the number of environmental variables by summarizing parts of the

Table 5. Habitat characteristics measured, estimated, observed, or calculated at selected sites in the upper Illinois River Basin

[ft, feet; ft^3/s, cubic feet per second]

The superscript ^{c} indicates that the characteristic was calculated from Illinois Environmental Protection Agency data. The superscript ^{ph} indicates that the characteristic was summarized by use of the mean value of phi. The term "percent" refers to the proportion of the streambed that consisted predominantly of the indicated type of substrate.

Habitat characteristic	Number of stations	Maximum	Minimum	Used for relational analyses?
Stream:				
Order	66	5	1	Yes
Average width (ft)	66	236	4.5	Yes
Average depth (ft)	66	4.4	.2	Yes
Average current velocity	66	4.3	.1	Yes
Discharge (ft^3/s)	66	1,160	.2	Yes
Percent pool	8	100	8	No
Percent riffle	24	90	0	No
Percent shade	54	90	0	Yes
Streambed substrates:				
Mean phi-value^c				Yes
Percent claypan	56	30	0	No^{ph}
Percent silt	56	99	0	No^{ph}
Percent sand	56	44	0	No^{ph}
Percent fine gravel	56	34	0	No^{ph}
Percent medium gravel	56	33	0	No^{ph}
Percent coarse gravel	56	33	0	No^{ph}
Percent small cobble	56	47	0	No^{ph}
Percent large cobble	56	47	0	No^{ph}
Percent boulder	56	27	0	Yes
Percent bedrock	56	78	0	Yes
Percent plant detritus	56	10	0	Yes
Percent logs	56	9	0	Yes
Percent cover	66	50	0	Yes
Percent vegetation	56	16	0	Yes
Percent other	56	44	0	Yes
Total number of variables used				14

water-quality, streambed-sediment-quality, and habitat data, and (3) identification and description of relations between patterns in fish-community structure and patterns in water quality, streambed-sediment quality, and habitat.

Major patterns in fish-community structure were summarized and described through DCA and the AIBI. The number of environmental variables used for correlative analyses with fish-community structure were reduced through principal components analysis and the calculation of a variable (mean phi-value) that describes substrate particle size. Relations between patterns in fish-community structure and water quality, streambed-sediment quality, and habitat were evaluated through correlative and graphical analyses. A detailed description of each component of the analysis follows.

Summarization of Patterns In Fish-Community Structure

The two sections that follow describe how DCA and the AIBI were used to summarize patterns in fish-community structure. The fish-community data were summarized to allow for patterns in the fish-community structure to be related to environmental variables.

Detrended Correspondence Analysis

DCA is an eigenvector ordination technique that identifies and describes patterns in community structure by summarizing the structure of a species-by-samples data matrix (Gauch, 1982). DCA mathematically defines a series of axes (ordination axes) that describe major patterns of association among species and samples. The first ordination axis describes the dominant structural pattern; subsequent axes describe subsidiary patterns and are orthogonal (uncorrelated) to previously extracted axes. The relative magnitudes of the eigenvalues of each axis provide a means of evaluating the relative importance of the axes. Detailed explanations of DCA can be found in Gauch (1982) and Ter Braak (1988).

DCA gives each sample and each species ordination scores that describe their position along each ordination axis. Species that are distributed similarly among samples will have similar ordination scores. Species that are not found together will have dissimilar ordination scores. The same is true for samples. The relative similarity of each sample (or species) can be displayed graphically by plotting each sample's (or species') scores on any two ordination axes as the x and y coordinates. This display, called an ordination diagram, is described by Gauch (1982, p. 109) as an "...arrangement of species and samples in a low-dimensional space such that similar entities are close by and dissimilar entities are far apart."

DCA was done on each of the fish-community data sets by use of the CANOCO computer program with polynomial detrending (Ter Braak, 1988). Preliminary analyses were done on raw data, presence/absence data, relative-abundance data, and the natural logarithms of the raw species-abundance data. Results presented here were obtained from the natural logarithms of the raw data. Other investigators also have found a logarithmic, or approximately logarithmic, transformation to be appropriate for DCA (Green, 1979; Gauch, 1982).

Deviant samples were identified by their appearance as outliers in preliminary ordination plots; deviations were confirmed by subsequent examination of the raw data. Deviant samples are those in which otherwise rare and uncommon species are unusually abundant (Gauch, 1982; Ter Braak, 1988). The effect of deviant samples was removed by assigning these samples a negligible weight (0.01) for subsequent analyses. This approach prevents deviant samples from affecting the calculations that extract the ordination axes but still enables the calculation of their ordination scores (Ter Braak, 1988).

The effect of rare and uncommon species was investigated by redoing each ordination after deleting species that were found in fewer than 3 percent of the samples. Deleting these species did not result in any substantial changes in the distribution of station ordination scores.

Alternate Index of Biotic Integrity

The AIBI is a modified and calibrated version of the IBI (Karr and others, 1986). The State of Illinois uses the AIBI as a biological variable in water-quality monitoring programs and for stream characterization and classification (Hite and Bertrand, 1989). The AIBI is calculated by summing the scores of 12 individual metrics that express ecologically meaningful information about the composition of the fish community. The metrics used for the AIBI are identical to those proposed by Karr and others (1986) for Illinois streams. The AIBI differs from the IBI in the calculation of the disease metric, which is set equal to the average of the other 11 metrics. This adjustment enables the calculation of an IBI-style index when data for disease and condition observations are not available (Hite and Bertrand, 1989).

The State of Illinois has calibrated the scoring criteria for the AIBI metrics to reflect (1) sampling methods that are used by the IDOC and the IEPA, (2) stream order, and (3) different regions of Illinois (Hite and Bertrand, 1989). All of the AIBI scores that are used in this report were obtained from the intensive basin survey reports (Illinois Environmental Protection Agency, 1987b, 1988a, 1988b).

Reduction of the Number Of Environmental Variables

The data that were selected for analysis include information for 75 water-quality constituents or properties, 23 habitat characteristics, and 18 streambed-sediment-quality constituents. If all of these variables were retained for indirect gradient analysis, the evaluation and interpretation of at least 116 different correlations would be required (1 for each variable with at least 1 DCA axis). The use of additional DCA axes and AIBI scores would increase that number dramatically.

The number of possible correlations was reduced by use of proxy variables to represent groups of several highly correlated variables and by summarizing the substrate particle-size information with a single variable.

Principal Components Analysis

Principal components analysis (PCA) was used to summarize subsets of the water-quality and streambed-sediment-quality data by identifying groups of constituents that are highly correlated. These groups of correlated constituents were evaluated; if appropriate, one variable was selected to serve as a proxy for the entire group. Proxy variables were then used to represent the entire group in analyses of relations between fish-community structure and quality of water and streambed sediments.

PCA is a factor-analytic technique that summarizes the variance-covariance or correlation structure of a data set by identifying major axes of variation within the data matrix (Davis, 1986). These axes, called principal components, are linear combinations of the original variables (Johnson and Wichern, 1982, p. 362). The first principal component expresses as much of the total system variability as can be explained by a single axis. Successive principal components each express some of the remaining variability and are orthogonal (uncorrelated) to previously derived principal components. Detailed discussions of PCA are found in Johnson and Wichern (1982), Pielou (1984), and Davis (1986).

PCA and DCA are eigenvector ordination techniques that provide a parsimonious description of the internal structure of complex multivariate data sets. In fact, many ecologists used PCA to summarize species-by-samples data matrices until Whittaker (1967) introduced correspondence analysis to the ecological community (Ter Braak, 1988). PCA is appropriate for analyzing data that have an underlying linear structure, criteria often met by water-quality data. DCA, on the other hand, does not require the assumption of a linear structure and is more appropriate for analyzing data that reflect the Gaussian response curves that theoretically describe relations between species abundance and environmental gradients (Ter Braak, 1986).

The total system variance of the original water-quality data set can be expressed by use of all of the principal components or all of the original data. The value of PCA, however, is that a large proportion of the total system variance is expressed by a small number of principal components. The principal components can be thought of as latent variables that provide a parsimonious means of expressing the variance of the original data. Because of this, a few principal components can replace the original variables and the loss of information is minimal (Johnson and Wichern, 1982).

Principal component scores can be calculated for each station and used to replace the original environmental variables in correlation analyses (Davis, 1986). In this study, however, PCA was used to identify water-quality and streambed-sediment-quality variables that could be used as proxies for groups of variables that are closely associated with individual principal components.

The degree of association between a variable and a principal component is expressed by a measure called loading. Loading reflects "...the relative importance of a variable within a principal component..." (Davis, 1986, p. 537). If a group of variables all load heavily on a particular principal component, then the variables express similar information. One variable can then be used as a proxy for the entire group of closely associated variables.

PCA was done on a subset of water-quality data that included 77 samples comprising 36 variables (table 4). Among these are four major ions, three forms of nitrogen, two forms of phosphorus, seven trace elements, four priority pollutants, and general properties such as hardness as calcium carbonate, electrical conductance, and chemical oxygen demand. These variables were selected on the basis of (1) the likelihood of their exhibiting large diel variability, (2) the number of samples with missing data, and (3) the proportion of the samples with concentrations less than the detection limit.

Dissolved oxygen, pH, and water temperature were not used for PCA because they are likely to exhibit large diel fluctuations. This variability can mask differences among sites. Variables with fewer than 72 observations (samples) were excluded because PCA requires a balanced data set. Including these variables would have greatly reduced the total number of samples available for PCA. For certain variables, values in more than 55 percent of the samples were less than the detection limit; these variables were not selected because preliminary results showed that including them caused unstable results.

PCA was done on a subset of the streambed-sediment-quality data that included 80 samples comprising 17 variables (table 4). Data for heptachlor epoxide were not used because more than 60 percent of the observations were less than the detection limit (table 4).

Data were transformed to approximate normality by use of the natural logarithms for PCA. The Pearson product-moment correlation matrix was used as the initial dispersion matrix. Use of the Pearson product-moment correlation matrix standardizes the data (Davis, 1986, p. 536). Principal components having eigenvalues greater than 1 were retained and rotated by use of the varimax procedure (Davis, 1986, p. 555). The loadings of variables on these rotated components were then assessed, and one or two closely associated variables were selected as proxies for each principal component.

Determination of Mean Phi-Values for Substrate Particle Size

At 56 of the fish-community-sampling stations, IEPA investigators estimated the percentage of the sampling area in which the predominant substrate belonged to one of nine particle-size classes (table 5). Data for eight of these classes (clay to large cobble) were summarized by calculating the mean phi-value for each station.

Phi is defined as the negative logarithm to the base 2 of the median particle size, as measured in millimeters. Phi-values are commonly used by sedimentologists to express particle-size distributions. The phi-scale was first introduced by Krumbein (1934) as a logarithmic transformation of the breakpoints in the Wentworth particle-size scale. Krumbein (1934) used the negative logarithm so that the largest particles would receive the smallest phi-values. This transformation results in plots that display the largest phi-values on the left-hand side, a longstanding tradition in sedimentology (Blatt and others, 1980).

Mean phi-values were calculated from the value of phi for each of the eight particle-size classes and the proportion of the substrate that dominated by each class. Each IEPA particle-size class was assumed to correspond to the Wentworth scale particle-size class of the same name. Phi-values for the particle-size classes were obtained from Guy (1969) (table 6). IEPA data provided the proportion of the substrate that was dominated by each particle-size class. These proportions were used as weighting factors to calculate the mean phi-value for the particle-size classes observed at stations for which the appropriate data were available.

Identification and Description of Relations Among Fish-Community Structure and Water Quality, Streambed-Sediment Quality, and Habitat

Relations between fish-community structure and water quality, streambed-sediment quality, and habitat were evaluated through nonparametric correlation, graphical analyses, and statistical tests of differences among groups of stations.

For the first step, Spearman's rho, a nonparametric correlation coefficient, was used to identify environmental variables most closely related to fish-community structure. This was done by examining correlation coefficients between DCA station scores, AIBI scores, and selected environmental variables. Correlations having a p-value less than 0.05 were considered significant. A total of 53 environmental variables were used: 35 water-quality variables, 4 streambed-sediment-quality variables, and 14 habitat variables (tables 4 and 5). If there are no ties in the data set, Spearman's rho is equivalent to the Pearson product-moment correlation on the ranks of the data (Conover, 1980, p. 252).

Water-quality and streambed-sediment-quality variables that were reported as being less than the detection limit were set to one-half the detection limit. This convention ensured that all less-than values were given a smaller rank than values at or above the detection limit.

Table 6. Phi-values used to calculate mean phi-values for Illinois Environmental Protection Agency intensive basin survey stations in the upper Illinois River Basin

[IEPA, Illinois Environmental Protection Agency; --, not applicable. Modified from Guy (1969, table 2, p. 7)]

IEPA particle-size classes	Wentworth-scale particle-size classes	Size range (millimeters)	Phi-values used to calculate means
Large cobbles	Large cobbles	256 -128	-8
Small cobbles	Small cobbles	128 - 64	-7
	Very coarse gravel	64 - 32	--
Coarse gravel	Coarse gravel	32 - 16	-5
Medium gravel	Medium gravel	16 - 8	-4
Fine gravel	Fine gravel	8 - 4	-3
	Very fine gravel	4 - 2	--
Sand	Very coarse sand	2 - 1	--
	Coarse sand	1 - .5	--
Sand	Medium sand	.5 - .25	1
	Fine sand	.25 - .125	--
	Very fine sand	.125 - .062	--
Silt	Coarse silt	.062 - .031	--
Silt	Medium silt	.031 - .016	5
	Fine silt	.016 - .008	--
	Very fine silt	.008 - .004	--
Claypan	Coarse clay	.004 - .0020	--
Claypan	Medium clay	.0020- .0010	9
	Fine clay	.0010- .0005	--
	Very fine clay	.0005- .00024	--

The second step was graphical examination of relations between significantly correlated environmental variables and fish-community structure by use of bivariate plots and boxplots. Bivariate plots of fish-community variables (DCA station scores or AIBI scores) and environmental variables were used to evaluate the results of the correlations. Boxplots were used to evaluate and display the relative magnitude of DCA station scores, AIBI scores, and environmental variables for different groups of sampling stations.

The final step was to evaluate the statistical significance of differences between groups of stations by use of the Kruskal-Wallace test and the Tukey-Kramer procedure for multiple comparisons (Sokal and Rohlf, 1981). The Kruskal-Wallace test is a nonparametric test of the null hypothesis that the distribution of a variable is the same among all groups. If this hypothesis was rejected (alpha = 0.05), then the Tukey-Kramer multiple-comparison procedure was done on ranked data to determine which groups were significantly different. The Tukey-Kramer procedure controls the experimentwise error rate, which was set at alpha equal to 0.05 (Sokal and Rohlf, 1981).

RESULTS OF PRINCIPAL COMPONENTS ANALYSIS

Water-Quality Data

PCA of the subset of 36 water-quality variables yielded 6 principal components with eigenvalues greater than 1. Together, these principal components account for 83 percent of the total variance. The loadings indicate that 6 variables can be used as proxies for 20 other variables that also load heavily on these principal components (table 7). The six proxy variables are (1) total recoverable sodium, (2) hardness as calcium carbonate, (3) total suspended solids, (4) total recoverable manganese, (5) total recoverable barium, and (6) total recoverable nickel (table 7).

Total recoverable sodium was selected as a proxy for the group of variables expressed by the first

Table 7. Varimax-rotated loadings of water-quality variables on the first six principal components

[Loadings for groups of closely associated variables are shown in bold print. Names of proxy variables for these groups are also in bold print]

Water-quality constituent or property	Principal component					
	1	2	3	4	5	6
Potassium, dissolved	**0.95644**	0.14247	0.08755	0.04132	-0.03123	0.10958
Potassium, total recoverable	**.95457**	.12908	.13228	.04343	-.02252	.10353
Sodium, total recoverable	**.93562**	.11443	.15175	.09540	-.13775	.00632
Sodium, dissolved	**.93528**	.11059	.16036	.09456	-.13561	.01481
Phosphorus, dissolved	**.88201**	-.19867	.11158	-.17772	.12284	-.07634
Boron, total recoverable	**.88000**	.08740	.15168	.17333	-.18669	.14696
Boron, dissolved	**.87320**	.09415	.13002	.18207	-.20124	.17013
Fluoride, total	**.87002**	-.08699	.06784	-.02898	-.04524	.22743
Phosphorus, total	**.86949**	-.15380	.26083	-.13526	.14785	.02288
Strontium, total recoverable	**.84231**	.32031	.04865	-.01084	.01477	.24564
Strontium, dissolved	**.84186**	.32286	.04723	-.00170	.00839	.24625
Dissolved solids	.77583	.57342	-.02940	-.01425	-.02144	.06598
Specific conductance	.73285	.60936	-.10715	.00348	.03889	.08367
Sulfate, dissolved	.73115	.45974	.07008	.02423	-.15377	.02557
Nitrogen, ammonia, total	.65833	-.31735	.15176	.33464	.20876	-.03023
Nitrogen, total kjeldahl	.50023	-.21206	.35822	.14757	.29615	.01729
Arsenic, total	.47282	-.18814	.33392	.34061	-.20158	-.04230
Magnesium, total recoverable	-.00193	**.97824**	-.01764	.08715	.00681	-.00442
Magnesium, dissolved	-.00638	**.97600**	-.04351	.10146	-.00850	.00542
Hardness, as calcium carbonate	.12476	**.96963**	-.13099	.02698	.06143	-.02586
Calcium, total recoverable	.24367	**.88033**	-.24862	-.06054	.13984	-.04307
Calcium, dissolved	.23507	**.87241**	-.28508	-.04462	.12113	-.04829
Suspended solids, total	.09971	-.10678	**.93689**	.05037	.02892	-.02703
Suspended solids, volatile	.12030	-.09616	**.88506**	-.09208	-.06824	-.07488
Iron, total recoverable	.09229	-.14875	**.87362**	.29443	.05660	-.05219
Turbidity, NTU	.23059	-.20531	**.80585**	.15746	-.10098	.05903
Chemical oxygen demand	.49384	-.01384	.65250	.29576	-.07230	-.07358
Manganese, dissolved	.17161	.01466	.02911	**.90186**	.06171	.02008
Manganese, total recoverable	.08824	.05919	.51143	**.77868**	-.05110	.10773
Nitrogen, nitrate, total	.18128	-.26578	-.23274	-.56963	.40290	-.13884
Barium, total recoverable	-.34016	.30456	.02476	.16451	**.76383**	.05649
Barium, dissolved	-.34929	.41120	-.22596	.14510	**.67078**	.05745
Cyanide, total	.07482	-.04452	.01635	-.22110	.62373	.02706
Nickel, dissolved	.16279	.02243	-.23935	.07912	-.04853	**.85290**
Nickel, total recoverable	.29652	-.04506	.07067	.09184	.12656	**.82993**
Copper, total recoverable	.40079	-.21992	.40804	-.16650	.06156	.43123

principal component (PC1) (table 7). Variables in this group are commonly associated with urban sources that include wastewater-treatment-plant effluents, industrial discharges, and nonpoint urban runoff. Potassium, sodium, phosphorus, boron, fluoride, and strontium are members of this group (table 7). In the upper Illinois River Basin, concentrations of sodium and potassium were largest in streams in urban areas receiving a large quantity of sewage effluent (Blanchard and Schmidt, in press).

Phosphorus is commonly associated with urban sources because of its use in detergents; it is also a byproduct of human metabolism (Hem, 1985). Boron is used in a variety of industrial processes and products, is highly soluble in water, and is not removed by conventional wastewater-treatment processes (Eisler, 1990). Fluoride is added to many public water supplies because it is believed that concentrations of approximately 1 mg/L help prevent tooth decay (Illinois Environmental Protection Agency, 1987a).

Strontium, also a member of the group represented by sodium, is not usually associated with industrial or wastewater effluents (Hem, 1985) but is commonly a component of limestone and dolomite. Strontium concentrations can be large in ground water pumped from limestone or dolomite aquifers (Hem, 1985). The association of strontium with urban point and nonpoint sources might be caused by patterns of ground-water use in the study area. In 1980, 21 public-water-supply centers in the Chicago metropolitan area each withdrew at least 2 million gallons of ground water per day from deep Cambrian-Ordovician aquifers (Burch, 1991, p. 25). This ground water enters the municipal-supply system and eventually enters streams as a point-source effluent or overland runoff. The Cambrian-Ordovician aquifer contains dolomite, and strontium concentrations as high as 4.7 mg/L have been observed in water samples collected from this system (Voelker and others, 1988, p. 467). This concentration of strontium is greater than any sample in the water-quality data set.

Hardness was selected as a proxy for the second principal component (PC2), which expresses the variance of calcium, magnesium, and hardness (table 7). Sources of calcium and magnesium in the study area include surficial deposits of glacial till and underlying limestone and dolomite bedrock. As a result, concentrations of these constituents tend to be large throughout the basin (Blanchard and Schmidt, in press).

Total suspended solids was selected as a proxy for the third principal component (PC3). PC3 also expresses the variance of volatile suspended solids, total recoverable iron, and turbidity (table 7). These constituents and properties are either measures of or are closely associated with the amount of suspended particulate material. The particles may be organic (such as phytoplankton) or inorganic (such as suspended sediment). Total suspended solids and volatile suspended solids are fairly direct measures of particulates. Turbidity is heavily influenced by the amount of suspended particulates. Total recoverable iron is not a direct measure of particulates; when iron is present in streams, however, nearly all of it is partitioned in the particulate phase (Horowitz, 1991).

The total recoverable fractions of manganese, barium, and nickel were selected as proxies for principal components 4 through 6 (PC4, PC5, PC6). These principal components express the variance of the dissolved and total recoverable fractions of these constituents (table 7). Total cyanide also loads heavily on PC5 (table 7), but it was retained as an individual variable because it is a USEPA priority pollutant (U.S. Environmental Protection Agency, 1986).

The 6 proxy variables for PC1 through PC6 represent the variability of 26 of the 36 variables in this subset of the water-quality data. Loading patterns for 9 of the 10 remaining variables indicated that their variance is split between 2 principal components (table 7). The 10th variable, total cyanide, was discussed previously.

Of the 10 variables not adequately explained by a single principal component, 6 were retained for further analyses and 4 were eliminated from further consideration. The six variables retained for further analyses are (1) total ammonia, (2) total nitrite plus nitrate nitrogen, (3) total arsenic, (4) chemical oxygen demand, (5) total cyanide, and (6) total recoverable copper. The four variables eliminated from further analyses are (1) dissolved solids, (2) specific conductance, (3) dissolved sulfate, and (4) total kjeldahl nitrogen.

Total ammonia was retained because it can be a major component of municipal wastewater-treatment-plant effluent and nonpoint urban runoff (Hill, 1981; cited in Blanchard and Schmidt, in press). Total nitrite plus nitrate nitrogen was retained because concentrations tend to be larger in agricultural areas of the upper Illinois River Basin than in urban areas (Blanchard and Schmidt, in press). Chemical oxygen demand was retained because it is commonly measured as an indication of general water quality. Total arsenic, total recoverable copper, and total cyanide were retained because they are priority pollutants.

Dissolved solids and specific conductance were excluded from further analyses because both are indirect measures of the total ionic strength of aqueous solutions. Total ionic strength, in turn, is a function of the major ions, which are explained by PC1 and PC2. Dissolved sulfate was excluded because the concentrations observed are unlikely to affect aquatic communities and because it is not a useful indicator of water-quality conditions that are likely to affect aquatic communities. Likewise, total kjeldahl nitrogen was eliminated from further analyses because it does not measure water-quality conditions that directly affect aquatic communities.

Streambed-Sediment-Quality Data

PCA of 17 streambed-sediment constituents yielded 3 principal components with eigenvalues greater than 1. Together, these three principal components account for 74 percent of the total variance of these data. Loadings of each variable on the three principal components are listed in table 8. These loadings indicate that 3 variables–total chromium, chemical oxygen demand, and total arsenic–can be used as proxies for 11 other variables that also load heavily on these principal components (table 8).

Total chromium was selected as a proxy for the group of variables that are expressed by the first principal component (PC1) (table 8). The variables in this group include five trace-element priority pollutants: chromium, zinc, lead, copper, mercury, and cadmium (table 8). Colman and Sanzolone (1992) showed that the concentration of these elements in streambed sediments of the upper Illinois River Basin is larger in urban areas than in agricultural areas and larger in high-order streams than in low-order streams. This pattern indicates that anthropogenic inputs from urban areas are possible sources of these constituents. Total polychlorinated biphenyls (PCB's), chlordane, and total dichlorodiphenyltrichloroethane (DDT) also loaded heavily to moderately on PC1 (table 8).

Chemical oxygen demand was selected as a proxy for the second principal component (PC2). Total kjeldahl nitrogen, chemical oxygen demand, and volatile solids all loaded heavily on PC2. Kelly and Hite (1984) also found that these constituents are highly intercorrelated in streambed sediments in Illinois.

Table 8. Varimax-rotated loadings of streambed-sediment-quality variables on the first three principal components
[Loadings for groups of closely associated variables are shown in bold print. Names of proxy variables for these groups are also in bold print]

Streambed-sediment-quality constituent	Principal component 1	Principal component 2	Principal component 3
Chromium, total	**0.92405**	0.22261	-0.01003
Zinc, total	**.90309**	.30285	-.00601
Lead, total	**.88585**	.30438	.03695
Copper, total	**.87271**	.37320	-.08289
Mercury, total	**.81884**	.46507	-.04708
Cadmium, total	**.81858**	-.00276	.14487
PCB's, total	**.81640**	.32877	-.15008
Chlordane	**.71759**	.43890	-.20164
DDT, total	**.68207**	.22622	-.21735
Phosphorus, total	.63099	.58689	.00331
Iron, total	.50161	.18397	.34346
Dieldrin	.43413	.25279	-.28925
Nitrogen, total kjeldahl	.10178	**.94067**	.07867
Chemical oxygen demand	.39657	**.83831**	.13017
Percent volatile solids	.34570	**.77698**	.07659
Arsenic, total	.17752	.22627	**.77370**
Manganese, total	-.30674	-.03701	**.69153**

Total arsenic was selected as a proxy for the third principal component (PC3). Arsenic and manganese both loaded heavily on PC3. Arsenic was selected as the proxy because it is of direct interest as a USEPA priority pollutant.

RELATIONS BETWEEN FISH-COMMUNITY STRUCTURE AND ENVIRONMENTAL CONDITIONS

Data Set 1–Nonwadable Sites

Results of Detrended Correspondence Analysis

The eigenvalues of the first four DCA axes extracted from the data set for nonwadable sites are 0.396, 0.193, 0.168, and 0.116. The relative magnitude of the eigenvalues indicates that the first DCA axis (axis 1) expresses a major pattern in fish-community structure. Examination of ordination plots and raw data indicated that the second axis (axis 2) primarily expressed the dominance of gizzard shad (48 percent of the catch) in the sample from station 74. The third and fourth axes did not express meaningful information. Only the major pattern expressed by DCA axis 1 is interpreted here.

Figures 6 and 7 are ordination diagrams that display the position of sampling stations and species along DCA axes 1 and 2. Positions along DCA axis 2 were plotted only so that stations and species are separated from one another in the ordination diagrams. Stations that are plotted near one another in figure 6 have similar fish communities. The positions of the 22 species that have the largest effect (largest weighting factors) in the calculation of the station scores are displayed in figure 7.

The major pattern in fish-community structure for nonwadable sites is associated with differences among basins. Boxplots of station scores on DCA axis 1, for each of four river basins, clearly demonstrate this pattern. Stations in the Chicago/Little Calumet and Des Plaines River Basins tend to have the smallest scores on DCA axis 1 (fig. 8). In contrast, stations in the Du Page River Basin tend to have slightly higher scores, and stations in the Fox River Basin have the highest scores.

The species-ordination diagram (fig. 7) shows the smallest scores on DCA axis 1; hence, stations in the Chicago/Little Calumet and Des Plaines River Basins are associated with fish communities primarily made up of goldfish, carp-goldfish hybrids, black bullhead, and gizzard shad. Low scores are also associated with black crappie, bluegill, fathead minnow, green sunfish, and creek chub.

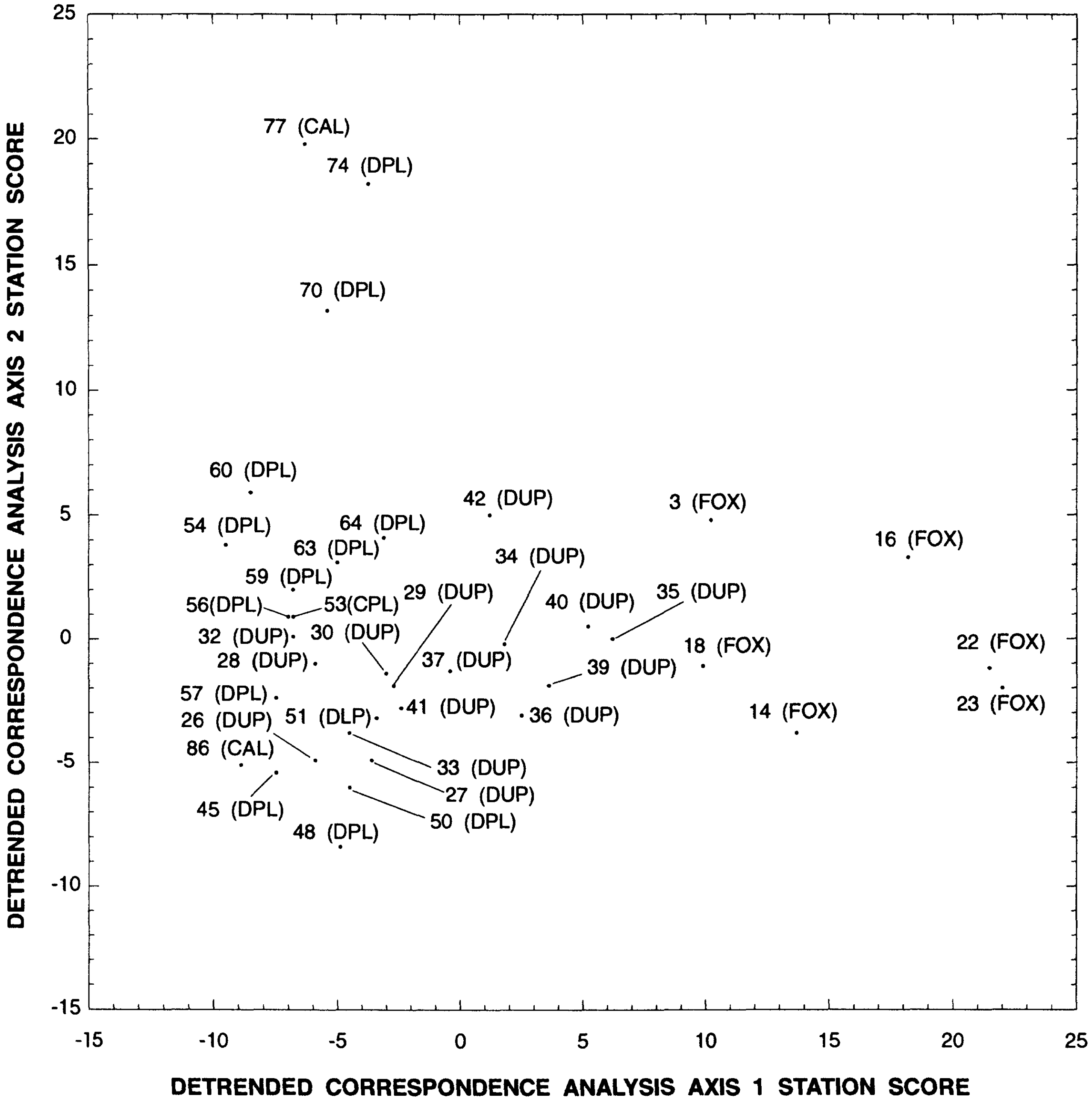
This association of species indicates that, for this data set, most of the stations in the Chicago/Little Calumet and Des Plaines River Basins had degraded water-quality and (or) habitat conditions and low stream gradients. Goldfish, carp-goldfish hybrids, and green sunfish generally dominate fish communities where water quality and (or) habitat are severely degraded (Smith, 1979; Becker, 1983). Large numbers of creek chubs may indicate habitat modification (Smith, 1979). Black bullhead, bluegill, and green sunfish are found in greatest abundance in areas with slow currents, such as low-gradient streams and pool habitats (Smith, 1979).

Stations in the Du Page River Basin tend to have higher scores on DCA axis 1 than samples collected in the Des Plaines River Basin (fig. 8). Of the 15 samples collected in the Du Page River Basin, 10 had higher scores on DCA axis 1 than any of the samples collected in the Des Plaines River Basin.

Stations in the Du Page River Basin were separated along DCA axis 1 from stations in the Des Plaines River Basin primarily because more species were captured at stations in the Du Page River Basin. Although many stations in both basins were dominated by carp and (or) green sunfish, the number of species captured (species richness) at stations in the Du Page River Basin greatly exceeded that of stations in the Des Plaines River Basin. The Du Page River Basin had 7 of the 10 stations with the greatest species richness in the entire data set, including the Fox River Basin. Many of the additional species captured at stations in the Du Page River Basin were present in small numbers but included species strongly associated with the structure of fish communities in the Fox River Basin. These species included shorthead redhorse, quillback, and northern hog sucker.

In addition, species classified by the State of Illinois as intolerant of high turbidity, siltation, organic enrichment, and habitat modification (Hite and Bertrand, 1989) were captured more often and in greater numbers at stations in the Du Page River Basin than at stations in the Des Plaines River Basin. Samples collected at 9 of 15 (60 percent) stations in the Du Page River Basin included intolerant species, whereas samples from 6 of 16 (38 percent) stations in the Des Plaines River Basin included intolerant species. The difference between these basins was greater if one considers the number of intolerant species found at each station. In the Du Page River Basin, samples from six of the stations contained more than one intolerant species; in the Des Plaines River Basin, however, more than one intolerant species was found at just one station.

Samples collected at six stations in the Fox River Basin have the highest scores on DCA axis 1 (fig. 8). The species-ordination diagram (fig. 7) shows that high scores on DCA axis 1 are associated with communities that had a high proportion of shorthead redhorse, quillback, golden redhorse, and northern hog sucker. Both of the redhorse species and the northern hog sucker are found in greatest abundance in clear, swiftly flowing streams underlain by firm pebbly, gravelly, and sandy bottoms. Shorthead redhorse and northern hog sucker, which are both classified as intolerant species (Hite and Bertrand, 1989), do



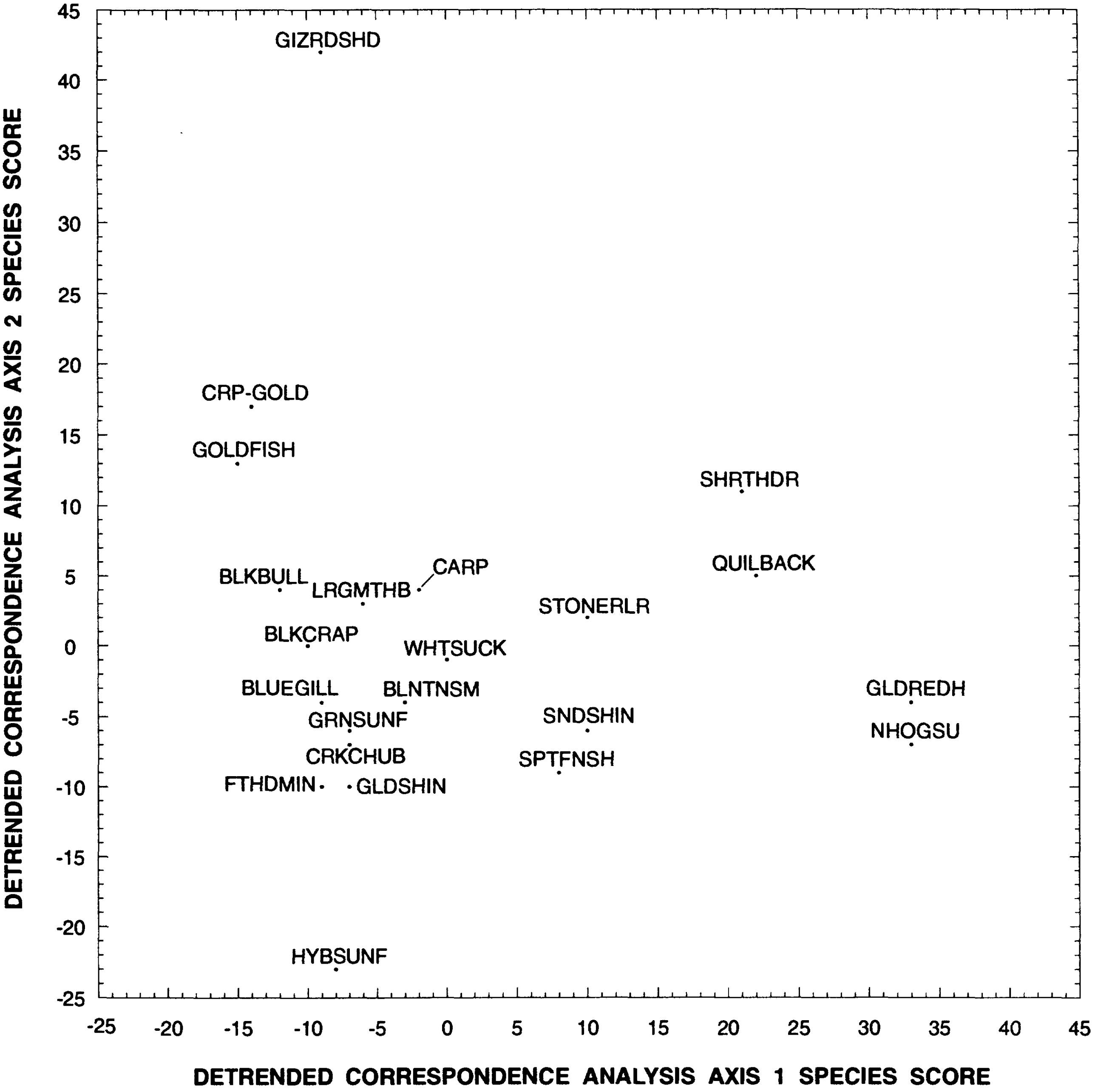
EXPLANATION

34(DUP) STATION NUMBER AND BASIN DESIGNATION--Refer to table 1

BASIN DESIGNATION

CAL	Little Calumet River Basin
DPL	Des Plaines River Basin
DUP	Du Page River Basin
CHG	Chicago River Basin
FOX	Fox River Basin

Figure 6. Station-ordination diagram for nonwadable sites, upper Illinois River Basin.



EXPLANATION

GIZRDSHD	SPECIES NAME--Refer to table 2

Figure 7. Species-ordination diagram for nonwadable sites, upper Illinois River Basin.

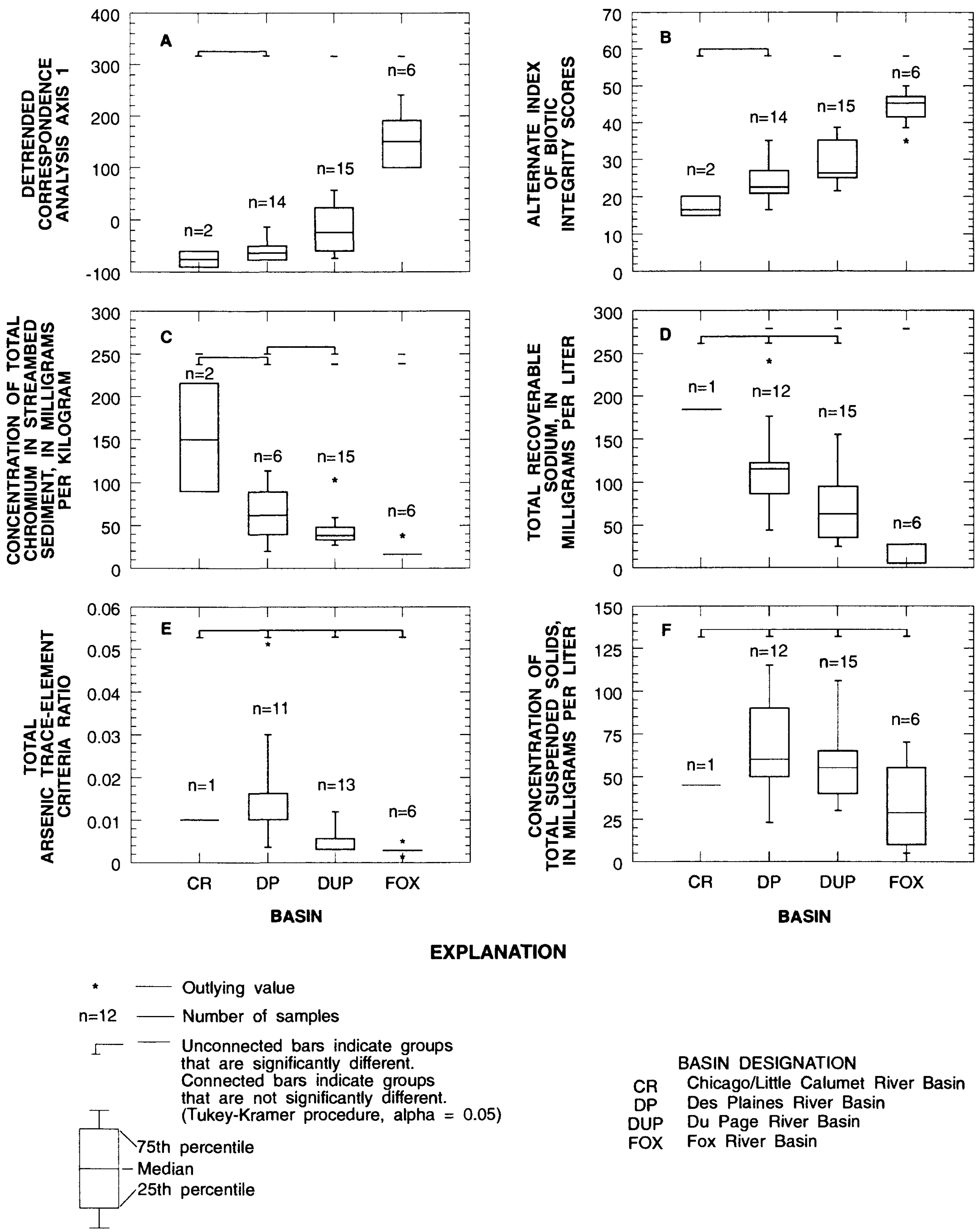


Figure 8. Boxplots of (A) detrended correspondence analysis (DCA) axis 1 station scores, (B) Alternate Index of Biotic Integrity (AIBI) scores, (C) concentration of total chromium in streambed sediments, (D) concentration of total recoverable sodium, (E) trace-element criteria ratio (TECR) for total arsenic, and (F) concentration of total suspended solids at stations in the Chicago/Little Calumet, Des Plaines, Du Page, and Fox River Basins. Results from DCA of fish-community data set 1, nonwadable sites.

not generally inhabit areas of silty bottoms and turbid water (Smith, 1979).

Multiple occurrences of intolerant species were common at stations in the Fox River Basin. From three to seven intolerant species were captured at each station. Four intolerant species–black redhorse, highfin carpsucker, rosyface shiner, and blacknose dace–were captured only in the Fox River Basin and not in the other basins. Inclusion of fish captured with seines at stations in the Fox River Basin would result in a more pronounced distinction compared with stations in the Du Page and Des Plaines River Basins.

Alternate Index of Biotic Integrity Scores

AIBI scores are significantly correlated with DCA axis 1 station scores (rho = 0.75, p = 0.0001) and have a similar pattern among the four river basins (fig. 8). As observed with DCA axis 1 scores, the Chicago/Little Calumet and Des Plaines River Basins have the smallest AIBI scores, the Du Page River Basin has intermediate AIBI scores, and the Fox River Basin has the highest AIBI scores. These results indicate that fish communities in the Chicago/Little Calumet and Des Plaines River Basins were more degraded than fish communities in the Du Page River Basin, which in turn were more degraded than fish communities in the Fox River Basin. This assessment corroborates the conclusions reached by examination of species associated with DCA axis 1.

Correlations of Fish-Community Structure With Water-Quality, Streambed-Sediment-Quality, and Habitat Variables

These patterns in fish-community structure are strongly related to water-quality and streambed-sediment-quality gradients commonly associated with urban sources. A total of 15 water-quality and streambed-sediment-quality variables are significantly correlated (p-value < 0.05) with DCA axis 1 station scores or with AIBI scores (table 9).

For DCA axis 1, the most highly correlated environmental variables were total chromium in streambed sediments (rho = -0.78) and total recoverable sodium in water (rho = -0.77). These variables are also highly correlated with AIBI scores (rho = -0.79 and -0.68, respectively; table 9). Both total chromium in streambed sediments and total recoverable sodium were selected as proxies for assemblages of constituents commonly associated with urban sources. Total chromium in streambed sediments is a proxy for nine other constituents, including five USEPA trace-element priority pollutants (copper, cadmium, lead, mercury, and zinc) and three synthetic organic compounds (chlordane, total PCB's, and total DDT). Total recoverable sodium is a proxy for an assemblage of 10 constituents, 8 of which are commonly associated with urban point and nonpoint sources (table 8).

The relation between patterns in fish-community structure and patterns in the concentration of these constituents can be seen by comparing boxplots of the concentration of these constituents to boxplots of DCA axis 1 station scores and AIBI scores (fig. 8). This comparison indicates that stations in the most heavily urbanized basins (Chicago/Little Calumet and Des Plaines River Basins) tend to have the smallest DCA axis 1 and AIBI scores and the largest concentrations of these constituents. In contrast, stations in the agricultural Fox River Basin have the largest DCA scores and AIBI scores and the smallest concentrations of these constituents.

Similar relations are observed for many of the other water-quality and streambed-sediment-quality variables that are inversely correlated with DCA axis 1 and AIBI scores (table 9). In general, larger concentrations were observed in the urbanized Chicago/Little Calumet and Des Plaines River Basins and smaller concentrations were observed in the more agricultural Fox River Basin.

Relations observed for the USEPA trace-element priority pollutants and for the concentration of un-ionized ammonia should be noted. Arsenic, nickel, copper, and chromium are USEPA priority pollutants where TECR's are significantly correlated with DCA axis 1 and AIBI scores (table 9). The criteria ratio for un-ionized ammonia is also significantly correlated with DCA axis 1 and AIBI scores. Boxplots for the arsenic TECR for each river basin are displayed in figure 8. The boxplots for arsenic (fig. 8) are representative of the boxplots for the other trace-element priority pollutants and for un-ionized ammonia. The largest concentrations were found in the Chicago/Little Calumet and Des Plaines River Basins, and the smallest concentrations were found in the Du Page and Fox River Basins (fig. 8). The values for the arsenic TECR are all at least an order of magnitude less than 1, however, which indicates that arsenic concentrations did not approach the USEPA acute criterion for the protection of freshwater aquatic

Table 9. Water-quality, streambed-sediment-quality, and habitat variables in the upper Illinois River Basin significantly correlated with detrended correspondence analysis axis 1 station scores and Alternate Index of Biotic Integrity scores: Fish-community data set 1, nonwadable sites

[DCA, detrended correspondence analysis; AIBI, Alternate Index of Biotic Integrity; rho, Spearman's rho; n, number of samples]

DCA score 1			AIBI score		
Environmental constituent or property	rho	n	Environmental constituent or property	rho	n
Chromium, total (sed)	-0.77594	29	Stream order	0.80872	22
Sodium, total recoverable	-.77270	34	Chromium, total (sed)	-.79031	29
Total arsenic criteria ratio	-.75329	31	Sodium, total recoverable	-.68138	34
Alternate Index of Biotic Integrity	.75150	37	Total nitrogen to total phosphorus ratio	.66072	32
Total nitrogen to total phosphorus ratio	.71250	32	Mean phi-value	-.65492	12
Mean phi-value	-.61538	12	Total arsenic criteria ratio	-.64627	31
Manganese, total recoverable	-.58075	34	Un-ionized ammonia criteria ratio	-.62535	34
Chemical oxygen demand (sed)	-.57572	29	Percent logs	-.60728	12
Chemical oxygen demand	-.56189	34	Nitrogen, ammonia, total	-.59019	34
Total recoverable nickel criteria ratio	-.54932	34	Manganese, total recoverable	-.58365	34
Arsenic, total (sed)	-.54315	29	Arsenic, total (sed)	-.51565	29
Total recoverable copper criteria ratio	-.53621	34	Total recoverable nickel criteria ratio	-.51454	34
Un-ionized ammonia criteria ratio	-.52514	34	Total nitrate to total ammonia ratio	.51226	34
Stream order	.50247	22	Percent cover	-.50965	22
Nitrogen, ammonia, total	-.49526	34	Chemical oxygen demand	-.50246	34
Total recoverable chromium criteria ratio	-.46768	34	Chemical oxygen demand (sed)	-.49061	29
Oxygen, dissolved	.36715	34	Total recoverable copper criteria ratio	-.47930	34
Total nitrate to total ammonia ratio	.36466	34	Suspended solids, total	-.40308	34
			Oxygen, dissolved	.37340	34
			Total recoverable chromium criteria ratio	.36651	34

life. This is also the case for nickel, copper, and chromium TECR's and for the un-ionized ammonia criteria ratio.

Only 3 of the 15 water and streambed-sediment constituents are positively correlated with DCA axis 1: the N/P ratio, the NO_3/NH_4 ratio, and dissolved oxygen. Large N/P and NO_3/NH_4 ratios are associated with agricultural areas in the upper Illinois River Basin (Blanchard and Schmidt, in press). This finding is consistent with the interpretation that fish-community structure is related to an urban gradient in water and streambed-sediment quality. Dissolved oxygen also is positively correlated with DCA axis 1. Dissolved-oxygen concentrations less than 5 mg/L were observed at only a few stations; thus, the data provide little evidence that dissolved-oxygen concentrations are directly affecting patterns in fish-community structure.

Of the water-quality and streambed-sediment-quality constituents, only total suspended solids is significantly correlated with AIBI scores but not with DCA axis 1 scores. Total suspended solids was selected as a proxy for an assemblage of variables that are associated with particulate material (table 7). The variability of total suspended solids within river basins is considerable (fig. 8). The Kruskal-Wallis test showed no significant difference (p-value = 0.1049) in the median concentrations of total suspended solids between basins. The significant correlation between total suspended solids and AIBI scores may be due to the sensitivity of the AIBI to the presence of species that are sensitive to habitat degradation caused by increases in turbidity and siltation.

Habitat conditions also may have affected the structure of fish communities at these stations, but the data are inconclusive. Phi, the variable used to summarize substrate particle size, is significantly correlated with DCA axis 1 and AIBI scores (table 9). Habitat data for many of the stations in this data set were incomplete or missing, however, so this correlation is based on data from only 12 stations, of which 11 are in the Du Page and Fox River Basins.

Stream order is highly correlated with AIBI scores (rho = 0.81; table 9). This relation indicates that large nonwadable streams tend to have higher AIBI scores, and thus more diverse fish communities, than small streams do. Stream order was moderately correlated with DCA axis 1 (rho = 0.50).

Data Set 2–Wadable Sites

Results of Detrended Correspondence Analysis

The eigenvalues of the first four DCA axes extracted from the data set for wadable sites are 0.421, 0.308, 0.193, and 0.174. The relative magnitudes of these values indicate that the first and second axes express the major patterns in fish-community structure. Examination of ordination plots and raw data indicated that the third and fourth axes did not express meaningful information. Only the first and second axes are interpreted here.

For the purpose of discussion, the station-ordination diagram was divided into four regions (fig. 9). The four regions are also shown on the species-ordination diagram, which displays the position of the 26 species that have the greatest influence (largest weighting factors) in the calculation of the station scores (fig. 10).

The river basins are not evenly represented in each region of the station ordination diagram (fig. 9). Region 1 was classified (cl.) as generally representing tributaries of the Fox River. Region 1 contains 15 of the 17 stations in the Fox River Basin and does not include any stations in the Chicago/Little Calumet, Des Plaines, or Du Page River Basins (table 10). Similarly, region 3 was classified as generally representing the Chicago/Little Calumet River Basin. Region 3 contains 8 of the 10 stations in the Chicago/Little Calumet River Basin and 4 stations from the Des Plaines and Du Page River Basins (table 10). Regions 2 and 4 were classified as Des Plaines River Basin regions. Regions 2 and 4 contain 15 of the 17 stations that are in the Des Plaines River Basin (table 10).

The species-ordination diagram (fig. 10) indicates that many region 1 stations, all in the Fox River Basin, were associated with species such as fantail darter, stoneroller, hornyhead chub, bigmouth shiner, northern hogsucker, smallmouth bass, and golden redhorse. Large numbers of southern redbelly dace and rosyface shiners also were captured at several of these stations. Most of these species reach their greatest abundance in cool, clear, swiftly flowing streams with gravel, cobble, or boulder substrates. Southern redbelly dace are usually associated with pool habitats in cool, clear streams. Fish communities that contain a large proportion of these species generally are found only where water quality and habitat are both good (Smith, 1979; Becker, 1983).

Some samples collected at stations displayed near the boundary of region 1 (fig. 10) contained large numbers of species most closely associated with regions 2, 3, or 4. These include green sunfish, creek chub, spotfin shiner, sand shiner, and redfin shiner (fig. 10). Stations displayed adjacent to region 2 tended to have large numbers of creek chub and green sunfish. Stations displayed adjacent to region 4 tended to have large numbers of spotfin shiner, sand shiner, and redfin shiner. In some cases, the spotfin, sand, and redfin shiners were the second or third most abundant species collected at boundary stations. Stations displayed in region 1, where these species were relatively abundant, however, also had at least moderate numbers of individuals of species that are more closely associated with region 1.

Table 10. Number of stations in each river basin that appear in each of the regions shown on the station-ordination diagram: Fish-community data set 2, wadable sites

Basin	Number of stations in each region			
	Region 1	Region 2	Region 3	Region 4
Chicago/Little Calumet Rivers	0	1	8	1
Des Plaines River	0	8	3	6
Du Page River	0	2	1	0
Fox River	15	1	0	1

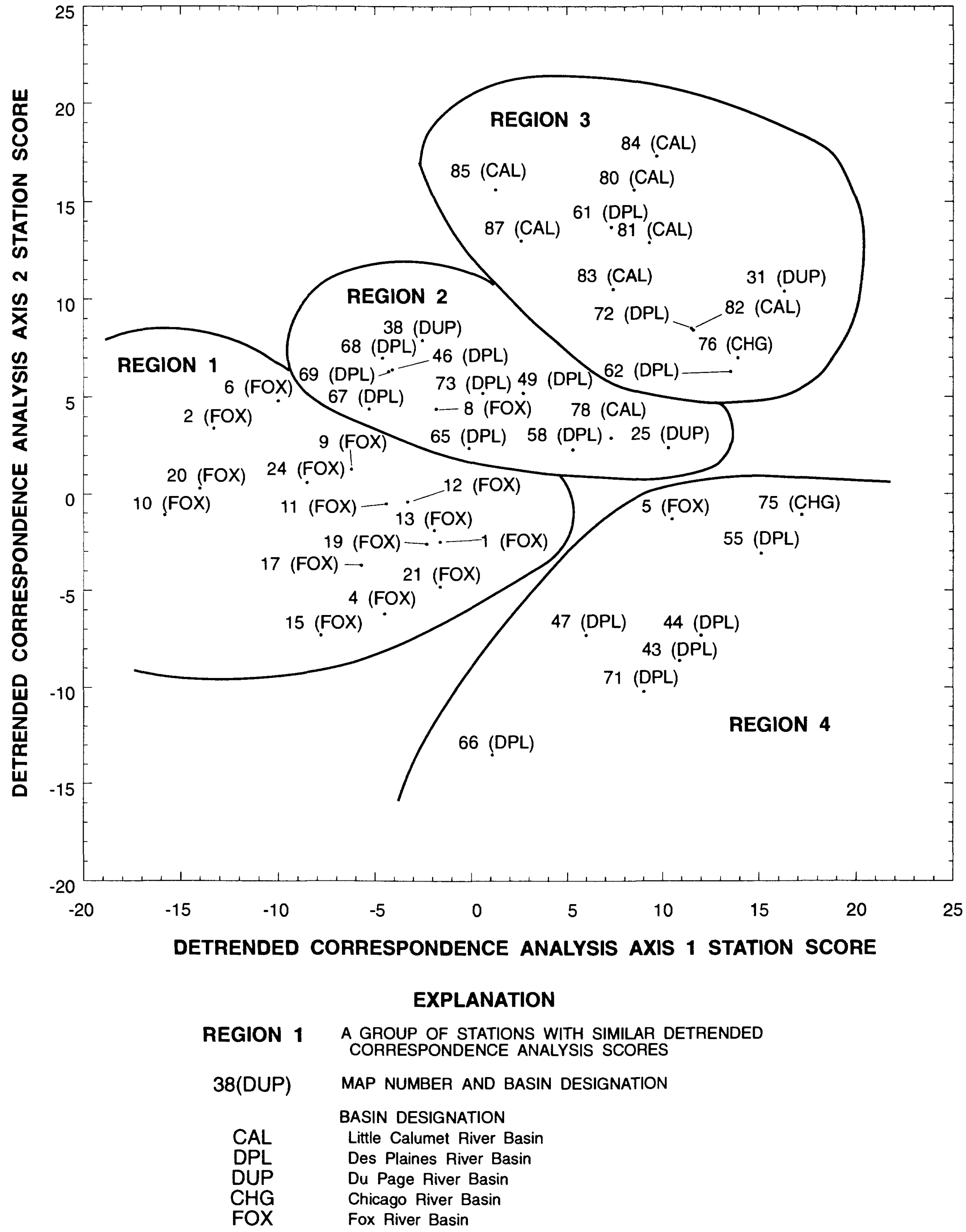
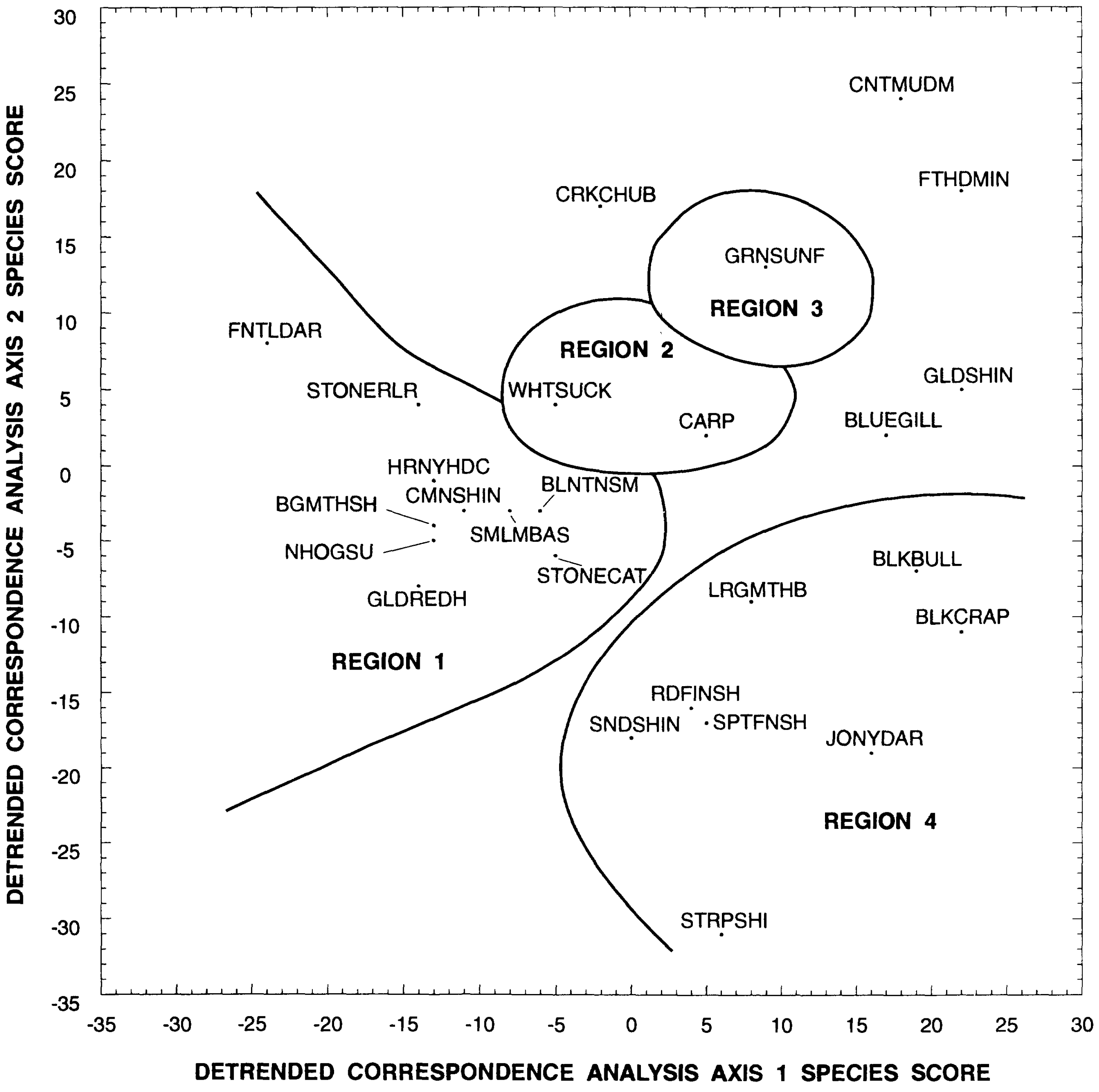


Figure 9. Station-ordination diagram for wadable sites, upper Illinois River Basin.



EXPLANATION

REGION 1	A GROUP OF STATIONS WITH SIMILAR DETRENDED CORRESPONDENCE ANALYSIS SCORES
CRKCHUB	SPECIES NAME--Refer to table 2

Figure 10. Species-ordination diagram for wadable sites, upper Illinois River Basin.

In contrast to stations displayed in region 1 (cl. Fox River Basin), fish communities at stations displayed in region 3 (cl. Chicago/Little Calumet River Basin) were dominated by species that are able to tolerate poor water quality and degraded habitat conditions. Stations displayed in region 3 were associated with large proportions of green sunfish, fathead minnow, and creek chub. These three species dominated the fish communities at many of these stations and often composed more than 70 percent of the total number of individual fish in a sample. As previously noted, large numbers of green sunfish and creek chub are indicative of degraded water quality and habitat (Smith, 1979; Becker, 1983). Fathead minnow are usually most abundant in sluggish creeks and ditches with mud bottoms (Smith, 1979).

Fish-community structure at stations displayed in region 2 of the ordination diagram (cl. Des Plaines River Basin) tend to be transitional combinations of the communities that are found at stations displayed in regions 1 and 3. Some examples of these combinations include fantail darter, green sunfish, and creek chub; creek chub and fantail darter; stoneroller and creek chub; stoneroller and green sunfish; common shiner and green sunfish; and green sunfish, creek chub, and hornyhead chub. Stations displayed in region 2 that were not dominated by a combination of species associated with regions 1 and 3 were often dominated by white sucker or carp.

These species associations indicate that most of the stations displayed in region 2 are on relatively small streams in the Des Plaines River Basin that contain high- and low-gradient habitats. Fantail darter, hornyhead chub, and stoneroller are most abundant in small streams with relatively high gradients (Smith, 1979; Becker, 1983). The presence of these species indicates a moderate to swift current. In contrast, creek chub and green sunfish are most abundant in small, low-gradient streams or pools (Smith, 1979; Becker, 1983).

Region 4 contains eight stations having fish communities that are not easily categorized (fig. 9). Six of these stations are in the Des Plaines River Basin, one is in the Chicago/Little Calumet River Basin, and one is in the Fox River Basin (table 10). Stations displayed in region 4 are associated with redfin shiner, spotfin shiner, sand shiner, largemouth bass, bluegill, black bullhead, and black crappie (fig. 10). These species indicate that many of these stations are probably on large, low-gradient streams in the Des Plaines River Basin. All but the redfin shiner are generally most abundant in streams greater than 39 ft in width (Becker, 1983). Except for the sand shiner and spotfin shiner, these species are most abundant in areas of low current velocities, such as pools, backwaters, and sloughs (Smith, 1979; Becker, 1983). In addition, black crappie, bluegill, and largemouth bass are commonly associated with low current velocities (Smith, 1979; Becker, 1983).

Stations in the lower left-hand part of the plot for region 4 tend to have large proportions of redfin shiners, spotfin shiners, and (or) sand shiners. Hickory Creek near New Lenox (map number 66) is an exception; 76 percent of the sample consisted of striped shiners. Samples at this station also contained black crappie, johnny darter, and sand shiner.

Stations in the upper right-hand corner of the plot for region 4 (fig. 9) tend to have a large proportion of green sunfish or fathead minnow (fig. 10). This accounts for their position in the station-ordination diagram (fig. 9). These stations are in region 4, however, because they have a relatively high number of at least one species that is associated with region 4. For example, the two most abundant species in the sample collected at station 5 are green sunfish (62 percent) and largemouth bass (11 percent). The large proportion of green sunfish in this sample resulted in its placement near the right side of the ordination diagram. The large proportion of largemouth bass led to its position in region 4, near the bottom of the ordination diagram.

A comparison of the presence of intolerant species (Hite and Bertrand, 1989) in samples illuminates differences in fish-community structure. From two to seven intolerant species were captured at every station displayed in region 1 (cl. Fox River Basin). In contrast, no intolerant species were captured at stations displayed in region 3 (cl. Chicago/Little Calumet River Basin). The presence of intolerant species at stations displayed in regions 2 and 4 (cl. Des Plaines River Basin) fell between these extremes. For region 2, samples from 4 of 11 stations contained intolerant species, and as many as 3 intolerant species were captured at a single station. For region 4, samples from six of nine stations contained intolerant species; as many as three intolerant species were captured at a single station.

In summary, regions 1, 2, and 3 of the ordination diagram express a distinct pattern, or gradient, in fish-community structure within the study area. The gradient ranges from fish communities that were dominated by species indicative of good water quality and habitat (region 1) through transitional communities that contained large numbers of intolerant and tolerant species (region 2) to communities that consisted almost entirely of species able to tolerate extremely degraded water quality and habitat (region 3).

The fish communities at stations displayed in region 4 of the ordination diagram were not as consistently similar to one another as those displayed in regions 1, 2, and 3. The most important shared characteristic among region 4 stations may be their dissimilarity with the fish communities in regions 1, 2, and 3 rather than their similarity to one another. Some stations displayed in region 4 were dominated by species that are indicative of degraded water quality and habitat. Some stations displayed in region 4, however, were dominated by species that are usually not associated with poor water quality or habitat. In addition, the presence of intolerant species at six of the eight stations in region 4 supports the contention that water quality and habitat at region 4 stations were not as severely degraded as water quality and habitat at stations displayed in region 3 of the ordination diagram (cl. Chicago/Little Calumet River Basin).

Alternate Index of Biotic Integrity Scores

Stations displayed in regions 1 and 4 of the ordination diagram (cl. Fox and Des Plaines River Basins) tended to have higher AIBI scores than stations displayed in regions 2 and 3 (cl. Des Plaines and Chicago/Little Calumet River Basins) (fig. 11). High AIBI scores indicate high-quality fish communities; low AIBI scores indicate low-quality, degraded fish communities. The Tukey-Kramer multiple comparison test indicated that median AIBI scores for regions 1 and 4 were not significantly different from one another but were significantly different from AIBI scores for regions 2 and 3. Median AIBI scores for regions 2 and 3 were not significantly different (fig. 11).

This pattern in AIBI scores is in general agreement with the interpretation of the results from DCA. The AIBI scores and DCA both indicate that stations displayed in region 1 had high-quality fish communities indicative of good water quality and habitat. The AIBI scores and DCA both indicate that stations displayed in regions 2 and 3 tended to have fish communities that were more degraded than those displayed in region 1. Both procedures indicate that fish-community structure within region 4 varied and that both high- and low-quality fish communities are displayed in that region of the ordination diagram.

Notable differences exist, however, between patterns expressed by DCA and the AIBI scores. DCA indicated that fish communities at stations displayed in region 2 of the ordination diagram differed from fish communities displayed in region 3. In contrast, AIBI scores tend to lump the stations in regions 2 and 3. AIBI scores for region 2 stations are not significantly different from those for region 3 stations (fig. 11). DCA also indicated that stations displayed in region 4 are not part of the pattern expressed by regions 1, 2, and 3. As one moves from region 1 through region 2 and into region 3, species are gradually replaced, and community composition shifts from species indicative of good water quality and habitat to species indicative of degraded conditions. DCA positioned region 4 stations outside this general pattern. Conversely, AIBI scores do not express that difference. There is no significant difference between AIBI scores for stations in region 4 and region 1 (fig. 11). Indeed, casual inspection of AIBI scores might lead to the conclusion that fish communities at stations in region 4 are intermediate between those in regions 1, 2, and 3.

Correlations of Fish-Community Structure with Water-Quality, Streambed-Sediment-Quality, and Habitat Variables

Correlative and graphical analyses indicate that fish-community structure is strongly related to water-quality gradients associated with differences between agricultural and urban land uses. Fish-community structure was unrelated, or only weakly related, to streambed-sediment quality. Fish-community structure was moderately related to factors associated with discharge or stream size and weakly related to other physical habitat characteristics.

DCA axis 1 shows that the dominant pattern in fish-community structure is strongly related to water quality. For DCA axis 1, the 10 highest correlations are with water-quality constituents (table 11). In contrast, three habitat characteristics (mean phi-value, percentage of vegetation, and current velocity) are significantly correlated with DCA axis 1. The correlation coefficients for these habitat variables are all

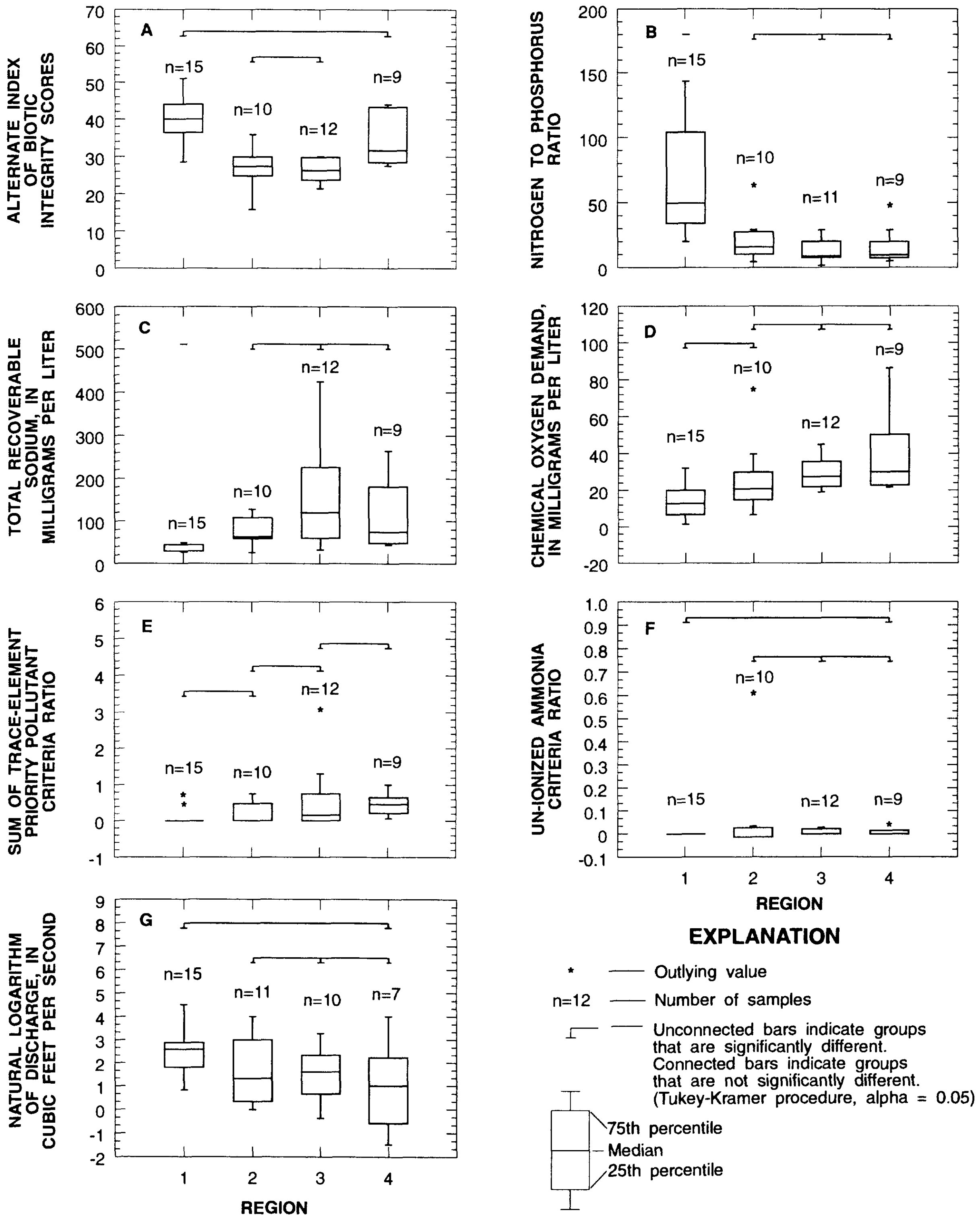


Figure 11. Boxplots of the (A) Alternate Index of Biotic Integrity (AIBI) scores, (B) nitrogen to phosphorus (N/P) ratios, (C) total recoverable sodium, (D) chemical oxygen demand, (E) sum of the trace-element priority pollutant criteria ratios (STECR), (F) un-ionized ammonia criteria ratios, and (G) natural logarithm of discharge for stations within four regions of the station-ordination diagram for fish-community data set 2, wadable sites, upper Illinois River Basin.

Table 11. Water-quality, streambed-sediment-quality, and habitat variables from selected sites in the upper Illinois River Basin that are significantly correlated with detrended correspondence analysis axis station scores and Alternate Index of Biotic Integrity scores: Fish-community data set 2, backpack electroshock and (or) minnow seining data

[DCA, detrended correspondence analysis; AIBI, Alternate Index of Biotic Integrity; rho, Spearman's rho; n, number of samples]

DCA Score 1			DCA Score 2			AIBI Score		
Environmental constituent or property	rho	n	Environmental constituent or property	rho	n	Environmental constituent of property	rho	n
Total nitrogen to total phosphorus ratio	-0.73467	46	Alternate Index of Biotic Integrity	-0.65132	47	Nitrogen, ammonia, total	-0.63415	46
Sodium, total recoverable	.69913	47	Discharge	-.49399	44	Total nitrate to total ammonia ratio	.60457	46
Chemical oxygen demand	.68295	47	Total nitrate to total ammonia ratio	-.45103	47	Sodium, total recoverable	-.58611	46
Sum of trace-element criteria ratios	.63586	47	Stream width	-.43928	44	Un-ionized ammonia criteria ratio	-.54608	46
Aluminum, total recoverable	.58242	13	Percent other	.40105	44	Total nitrogen to total phosphorus ratio	.50371	45
Nitrogen, ammonia, total	.55995	47	Nitrogen, ammonia, total	.38984	47	Barium, total recoverable	.45843	46
Un-ionized ammonia criteria ratio	.51171	47	Stream order	-.35598	44	Chemical oxygen demand (sed)	-.39830	41
Total recoverable copper criteria ratio	.49024	46	Oxygen, dissolved	-.35259	46	Discharge	.39504	43
Total nitrate to total ammonia ratio	-.45959	47	Sodium, total recoverable	.34603	47	Stream order	.38848	43
Suspended solids, total	.43041	47	Un-ionized ammonia criteria ratio	.31427	47	Mercury, total recoverable	-.35167	45
Sulfate, dissolved	.42865	47	Current velocity	-.31252	44	Plant detritus	-.34301	43
Total recoverable zinc criteria ratio	.42753	47				Oxygen, dissolved	.33189	45
Arsenic, total	.41544	45				Sulfate, dissolved	-.32984	46
Mean phi-value	.38975	44				Stream width	.31025	43
Alternate Index of Biotic Integrity	-.37785	47				Chemical oxygen demand	-.30362	46
Percent vegetation	.35402	44						
Hardness, as calcium carbonate	-.34856	45						
Barium, total recoverable	-.34527	47						
Oxygen, dissolved	-.31380	46						
Current velocity	-.30933	44						

low (0.39-0.31), and one of these variables (current velocity) is also significantly correlated with DCA axis 2 (table 11). DCA axis 1 is not significantly correlated with any of the streambed-sediment-quality variables (table 11).

For DCA axis 1, the N/P ratio and the concentration of total recoverable sodium are the two most highly correlated water-quality variables. The N/P ratio is inversely correlated with DCA axis 1 (rho = -0.73), whereas total recoverable sodium is positively correlated (rho = 0.70). The contrast between the direction of these relations indicates that DCA axis 1 is strongly related to water-quality gradients associated with differences between agricultural and urban water quality.

N/P ratios are highest in agricultural areas of the upper Illinois River Basin (Blanchard and Schmidt, in press). The N/P ratios tend to be highest for stations whose scores on DCA axis 1 are low. This result indicates that stations with low scores on DCA axis 1 are in agricultural areas. In contrast, the concentration of total recoverable sodium tends to be higher at stations with high scores on DCA axis 1. Total recoverable sodium is the proxy for an assemblage of constituents commonly associated with urban point-source discharges (table 7). This result indicates that stations with high scores on DCA axis 1 are on urban streams that receive substantial quantities of point-source effluents.

N/P ratios and the concentration of total recoverable sodium tend to differ among stations displayed in each region of the DCA ordination diagram (fig. 11). N/P ratios tend to be largest at stations displayed in region 1 and smallest at stations in regions 2, 3, and 4 (fig. 11). In contrast, the concentration of total recoverable sodium tends to be smallest in region 1 and largest in regions 2, 3, and 4 (fig. 11). The medians for the N/P ratio and the concentration of total recoverable sodium of region 1 are significantly different from medians for regions 2, 3, and 4.

Other water-quality constituents that are significantly correlated with DCA axis 1 and (or) DCA axis 2 (table 11) exhibit similar relations to land use. Stations displayed in region 1 tend to have small concentrations of constituents typically associated with urban sources, whereas stations in regions 2, 3, and 4 have larger concentrations. Although the statistical significance of these differences varies, the general tendency strongly indicates that patterns in fish-community structure are closely related to water-quality gradients commonly associated with differences between agricultural and urban land uses. Furthermore, these patterns indicate that water quality was similar among the stations displayed in regions 2, 3, and 4 of the ordination diagram (fig. 9). This relation of water-quality constituents to land use is further illustrated by chemical oxygen demand (fig. 11D), the STECR (fig. 11E), and the un-ionized ammonia criteria ratio (fig. 11F).

Although the STECR and the un-ionized ammonia criteria ratio are closely related to patterns in fish-community structure, it is unlikely that trace element or un-ionized ammonia concentrations were a major influence on the structure of fish communities in wadable streams. Only 2 of the 47 values for STECR are greater than 1; thus, the concentrations of individual trace-element priority pollutants were well below their respective acute toxicity criteria. Similarly, all of the un-ionized ammonia concentrations were well below the USEPA acute criterion. All but one of the samples had a concentration at least an order of magnitude less than the criterion (fig. 11).

DCA axis 2 is moderately correlated with stream discharge (rho = -0.49), average stream width (rho = -0.44), stream order (rho = -0.36), and average current velocity (rho = -0.31) (table 11). Large streams tend to have low scores for DCA axis 2, which indicates that DCA axis 2 expresses differences in fish-community structure associated with differences in discharge or stream size (fig. 11).

AIBI scores also are moderately correlated with stream discharge (rho = 0.40), stream order (rho = 0.39), and stream width (rho = 0.31). This correlation indicates that large streams tended to have high AIBI scores, which are indicative of higher-quality fish communities.

Discharge for stations displayed in region 1 (cl. Fox River Basin) is significantly higher than discharge for regions 2 and 3 (cl. Des Plaines and Chicago/Little Calumet River Basins) (fig. 11). Additionally, discharge at stations in region 4 (cl. Des Plaines River Basin) tends to be slightly lower than discharge at stations in region 1 and slightly higher than discharge at stations in regions 2 and 3. These differences, however, are not statistically significant (fig. 11).

AIBI scores follow a similar pattern (fig. 11). Discharge and AIBI scores for stations in regions 1 and 4 were more similar to one another than to discharge and AIBI scores for stations in regions 2 and 3. Discharge and AIBI scores both tended to be higher in regions 1 and 4 than in regions 2 and 3.

In summary, fish communities in region 1 (cl. Fox River Basin) consisted of species associated with good water quality and habitat. Compared to the other regions, region 1 had high AIBI scores. Region 1 also had smaller concentrations of water-quality constituents commonly associated with urban point-source effluents and tended to have higher discharges than stations in regions 2 and 3 (figs. 10 and 11).

Stations displayed in regions 2 and 3 (cl. Des Plaines and Chicago/Little Calumet River Basins) tended to have fish communities consisting of species that are associated with poor water quality and habitat. The AIBI scores are lower than for regions 1 and 4. Stations in regions 2 and 3 also had larger concentrations of water-quality constituents associated with urban point and nonpoint sources and tended to have lower discharges than stations in region 1 (figs. 10 and 11).

Stations displayed in region 4 of the ordination diagram (cl. Des Plaines River Basin) (1) tended to have fish communities that provide differing indications of water quality and also to include species that are indicative of areas with low current velocities, (2) tended to have AIBI scores that were lower than those for region 1 and higher than those for regions 2 and 3, (3) tended to have large concentrations of water-quality constituents commonly associated with urban point and nonpoint sources, and (4) tended to have lower discharges than stations in region 1 but higher discharges than stations in regions 2 and 3 (figs. 10 and 11).

DISCUSSION

The results of these analyses indicate that, during the early 1980's, fish-community structure within the study area was strongly related to patterns in water quality associated with differences between agricultural and urban land uses. The relations between fish-community structure and water quality were associated with assemblages of water-quality constituents rather than with individual constituents. This association was demonstrated by strong relations between fish-community structure and total recoverable sodium, a proxy for eight other constituents associated with urban point and nonpoint sources.

The data indicated a strong relation between the quality of the fish community and the overall water quality, despite the fact that USEPA acute criteria for the protection of freshwater aquatic life were rarely exceeded. USEPA acute water-quality criteria were exceeded for only three constituents: total cyanide (>22 μg/L), dissolved oxygen (<5 mg/L), and total recoverable copper (hardness dependent) (U.S. Environmental Protection Agency, 1986). Of these, the acute criterion for total cyanide was exceeded most often (10 stations), but total cyanide was not significantly correlated with DCA scores or AIBI scores. Furthermore, 6 of the 10 exceedances occurred at stations in the Fox River Basin, where fish communities tended to indicate good water quality.

The acute criterion for dissolved oxygen was exceeded at seven stations, but the relation between fish-community structure and dissolved oxygen tended to be relatively weak in comparison to that of other constituents. Bivariate plots of the dissolved-oxygen concentrations and fish-community variables (DCA scores and AIBI scores) indicated that stations where the dissolved-oxygen criteria were exceeded also were sites of degraded fish communities, but so were many of the stations where dissolved-oxygen criteria were not exceeded. Even if small dissolved-oxygen concentrations were exerting a major systemwide influence on these fish communities, the data in this study would probably not reveal it because most of the observations were made at midday, when dissolved-oxygen concentrations would have recovered from nighttime minimums.

Of the constituents whose concentrations exceeded USEPA acute criteria, only the total recoverable copper TECR was significantly correlated with fish-community structure for wadable and nonwadable sites alike. For nonwadable sites, this variable was significantly correlated with DCA axis 1 and AIBI scores. For wadable sites, the copper TECR was significantly correlated with DCA axis 1. The total recoverable copper criterion was exceeded at only two stations in the entire data set, however, which indicates that if copper concentrations are affecting the structure of fish communities, it is doing so at concentrations that are less than the USEPA acute criteria for the protection of freshwater aquatic life.

USEPA chronic criteria for the protection of aquatic life were not used to calculate criteria ratios (TECR, STECR, un-ionized ammonia criteria ratio) for correlative analyses because the chronic criteria apply to the 4-hour mean concentration, whereas the water-quality data consist of a single sample from each site.

A comparison of the water-quality data with the USEPA chronic criteria indicates that the criteria were exceeded for cyanide (5.2 µg/L), mercury, cadmium, copper (all hardness dependent), and un-ionized ammonia (pH and temperature dependent) (U.S. Environmental Protection Agency, 1986). Total cyanide exceeded the chronic criterion at 34 stations. As with the acute criteria, however, many of these stations are in the Fox River Basin, which, in comparison with the other basins, has high-quality fish communities. Total recoverable mercury exceeded the chronic criterion at 14 stations, but the mercury criterion reflects concerns about biomagnification rather than the effects of mercury on aquatic organisms (U.S. Environmental Protection Agency, 1986). Cadmium, copper, and un-ionized ammonia concentrations exceeded the chronic criteria at four or fewer stations. This is weak evidence that cadmium, copper, or un-ionized ammonia are responsible for the broad relation between fish-community structure and water quality shown here.

Fish communities in the study area may have been responding to these chemical constituents at concentrations smaller than the USEPA acute or chronic criteria. Alternatively, overall water quality may have been having a cumulative, or synergistic, effect on fish communities in the study area. If either hypothesis proved to be true, it would have serious implications for the design of large-scale, spatially oriented water-quality assessments. An assessment based on a comparison of chemical concentrations to USEPA criteria is at substantial risk of failing to accurately characterize the condition of water resources. This risk is probably enhanced if only a few water-chemistry samples are collected at each station.

Analyses of fish-community data, on the other hand, clearly indicated that environmental conditions in the urbanized parts of the study area were degraded relative to those in agricultural areas. In the most extreme urban situations, for example, the fish community consisted entirely of extremely tolerant species such as goldfish and common carp. DCA and AIBI scores revealed an overall pattern, or gradient, in environmental conditions that might have been missed by relying on water-quality data alone.

Fish-community structure for nonwadable sites was strongly related to the concentration of chemical constituents in streambed sediments, but this was not the case for wadable sites. Fish-community structure at nonwadable sites was most strongly related to total chromium in streambed sediments, which served as a proxy for an assemblage of constituents associated with urban settings (Colman and Sanzolone, 1992). This contrast between wadable and nonwadable sites might be attributable to differences in the size of the streams that are represented in each data set.

Large, nonwadable streams in the study area are included in data set 1; in the upper Illinois River Basin, large streams tend to have the largest concentrations of streambed-sediment constituents that are associated with urban sources (Colman and Sanzolone, 1992). The smaller, wadable streams are contained in data set 2; in the upper Illinois River Basin, smaller streams tend to have smaller concentrations of these constituents (Colman and Sanzolone, 1992). This difference is not attributable to any difference in the distribution of wadable and nonwadable streams in urban and nonurban settings. Many of the wadable streams in the data set are in the most urbanized parts of the study area. If relations between fish-community structure and streambed-sediment quality were strictly a function of differences between urban and agricultural settings, this should have been indicated by the analyses of data for wadable sites.

Fish-community structure was not as strongly related to habitat as it was to water quality and streambed-sediment quality. Substrate particle size was related to fish-community structure for wadable and nonwadable sites, but the evidence was weak either because the correlation coefficient was relatively small (wadable sites) or because sampling was incomplete (nonwadable sites). For nonwadable sites, the percentage of the sampling reach that contained logs and the percentage that contained fish cover were related to AIBI scores. As with phi-values, however, the evidence for this relation was weak because sampling was incomplete.

Fish-community structure for wadable sites was related to discharge, stream width, stream order, and current velocity but not as strongly as to water quality. These habitat variables were correlated with the second subsidiary DCA axis rather than with the first dominant DCA axis. Furthermore, the correlation coefficients with DCA axis 2 were moderate. Spearman's rho equaled -0.49, -0.44, -0.36, and -0.31 for discharge, stream width, stream order, and current velocity. In contrast, DCA axis 1 was strongly related to water quality (rho for total recoverable sodium = 0.70). At wadable sites, discharge was related to AIBI scores, but the correlation coefficient was smaller (rho = 0.40) than it was for the water-quality constituents that were significantly correlated with AIBI scores (for example, rho for total recoverable sodium = -0.59).

For wadable sites, differences in discharge between different regions of the ordination diagram indicate that, in some cases, fish-community factors related to discharge might ameliorate the effects of poor water quality. Stations in regions 2, 3, and 4 tended to have similar water quality. Fish communities in regions 2 and 3 are indicative of degraded water quality. Because of the similarity in water quality, one might expect fish communities in region 4 to be degraded as well. Many of the stations in region 4, however, had fish communities indicative of good water quality and had high AIBI scores. The major difference seems to be that many of the stations in region 4 tended to have higher discharges than stations in regions 2 and 3. This finding may be an indication that fish communities in high-biovolume streams responded differently from low-biovolume streams to poor water quality.

Bertrand (1984) and Sallee and Bergmann (1986) also noted that AIBI scores in the Des Plaines and Fox River Basins did not seem to be strongly related to habitat. Bertrand (1984) found that AIBI scores were relatively small in the Des Plaines and Du Page River Basins despite the presence of many areas with good or even excellent habitat. Sallee and Bergmann (1986) found that AIBI scores were not significantly correlated (Spearman's rho) with habitat characteristics.

The analyses reported here are based on combined analysis of the data sets analyzed separately by Bertrand (1984) and Sallee and Bergmann (1986). Combining those data and analyzing them as a whole maximizes the length of the fish-community and habitat gradients. This combination should increase the ability of investigators to discern relations between fish community and habitat because the combined data set includes a wider range of fish communities and habitats. The fact that analyses of the combined data set indicated that fish-community structure is more strongly related to water quality and streambed-sediment quality than to habitat is additional evidence that fish communities in the study area were generally not habitat limited.

This conclusion should be viewed with caution, however, because it might be due to limitations in the habitat data rather than to lack of such relations. As noted previously, the habitat data for many of the nonwadable stations are incomplete or missing. Many of the stations with missing habitat data were among those with the most degraded fish communities. Because these stations did not have complete sets of habitat data, they were excluded from the correlative analyses designed to identify relations between fish-community structure and habitat.

Another notable result is that, for these data, the results of analyses based on DCA and results of analyses based on AIBI generally agree or complement one another. For nonwadable sites, DCA axis 1 and AIBI scores were significantly correlated. This correlation indicates that each method identified the same general gradient in fish-community structure. This relation between DCA axis 1 and AIBI scores led to a high degree of similarity in their respective relations with environmental variables. Both methods for summarizing fish-community structure led to the same general conclusions regarding the relation between fish-community structure and environmental conditions for nonwadable sites.

For wadable sites, the first, and dominant, DCA axis was not significantly correlated with AIBI scores, but the second DCA axis was. This seems to indicate that for wadable sites, DCA and the AIBI scores identified different gradients in fish-community structure. This is true to a certain degree, but upon closer examination, it seems that DCA expressed basically the same information as the AIBI but split it between two axes. The first DCA axis expressed that portion of the pattern in fish-community structure that was strongly related to water quality. The second DCA axis expressed that portion of the pattern in fish-community structure that was strongly related to discharge and associated factors. The fact that DCA axis 1 expresses the dominant gradient in fish-community structure indicates that patterns in fish-community structure are more closely related to water quality than to discharge-related factors. An examination of the correlations between AIBI scores and the environmental variables results in the same conclusion. AIBI scores were more highly correlated with water-quality variables than with discharge. This indicates that the dominant pattern in fish-community structure, as expressed by the AIBI, is most closely related to water quality.

The similarity in the conclusions that are reached through DCA and through the AIBI lend credence to the use of multivariate techniques for regional water-quality assessments. Furthermore, this general agreement indicates that multivariate techniques can be a useful tool for validating the design of multimetric indices such as the AIBI. In this instance, the AIBI is a modification of an index (the IBI) that was specifically designed with Illinois streams in mind. Given the advanced development of the AIBI for Illinois, the substantial agreement between the two indices is not surprising. In other cases, however, where fully developed and tested indices are not available, multivariate ordination may be a useful tool for design and testing.

PCA was used to summarize the covariance among water-quality and streambed-sediment-quality variables by identifying groups of variables that were highly correlated. Although helpful, this approach was not entirely successful. Data for USEPA trace-element priority pollutants could not be summarized through PCA because too many values were reported as being less than the detection limit. Dissolved oxygen, pH, and water temperature were not used for PCA because their diel variability would have a tendency to mask spatial variability. Less-than values did not limit PCA of the streambed-sediment-quality data set, but the covariance among these variables was so high that nearly all were associated with the first principal component. This association hampered evaluation of the relations between trace elements in streambed sediments and fish-community structure separately from the relations that might be applicable for synthetic organic compounds.

SUMMARY AND CONCLUSIONS

Indirect gradient analysis of relations between fish-community structure, water-quality, streambed-sediment-quality, and habitat data collected between 1982 and 1984 in the Fox, Des Plaines, and Du Page River Basins in northeastern Illinois indicate that fish-community structure was strongly related to water-quality gradients often associated with differences between agricultural and urban land uses. Detrended correspondence analysis (DCA) and the Alternate Index of Biotic Integrity (AIBI) were used to summarize patterns in fish-community structure. Principal components analysis (PCA) was used to identify groups of water-quality and streambed-sediment constituents that covaried and could be represented by individual constituents. Correlations and graphical analyses were used to identify and describe relations between fish-community variables and environmental variables. The following is a summary of observations and conclusions.

1. DCA and AIBI scores tended to group fish communities by river basin.
2. Streams in the predominantly agricultural Fox River Basin tended to have similar DCA scores, the highest AIBI scores, and relatively diverse fish communities that usually included several intolerant species.
3. Streams in the more heavily urbanized Chicago, Little Calumet, Des Plaines, and Du Page River Basins tended to have lower AIBI scores and fish communities dominated by fewer, more tolerant species.
4. PCA showed that total recoverable sodium could be used as a proxy for an assemblage of water-quality constituents associated with urban point and nonpoint sources. PCA of streambed-sediment-quality data showed that total chromium could be used as a proxy for an assemblage of chemical constituents in streambed sediments associated with urban sources.
5. Correlative (Spearman's rho) and graphical analyses showed that DCA and AIBI scores for nonwadable sites were more strongly related to water quality and streambed-sediment quality than to habitat conditions.
6. Fish-community structure for nonwadable sites was strongly related to the concentration of chemical constituents in streambed sediments, but this was not the case for wadable sites.
7. DCA and AIBI scores for wadable sites were most strongly related to water quality, were not related to streambed-sediment quality, and were moderately related to habitat variables indicative of stream size. Streams in the Fox River Basin had the smallest concentrations of chemical

constituents often associated with anthorpogenic sources. Streams in the more heavily urbanized Des Plaines and Du Page River Basins had higher concentrations of chemical constituents associated with urban runoff and point-source discharges.

8. There was a strong inverse relation between the quality of fish communities in the study area and overall water quality despite the fact that USEPA acute criteria for the protection of freshwater aquatic life were rarely exceeded. These fish communities may have been responding to concentrations below the USEPA criteria or to cumulative or synergistic effects of overall water-quality conditions. This implies that large-scale, spatially-oriented water-quality assessments that rely on comparing chemical concentrations to USEPA criteria run a substantial risk of failing to accurately characterize the condition of water resources.
9. Analyses that utilized DCA to summarize fish-community structure were in close agreement with analyses that utilized the AIBI. The close agreement between DCA and the AIBI indicates that ordination methods such as DCA may be useful tools for regional water-quality assessments where IBI-style metrics have not been fully developed. Furthermore, it suggests that multivariate techniques can be useful tools for designing, testing, and validating multimetric indices such as the IBI.

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