SURFACE-WATER HYDROLOGY AND QUALITY, AND MACROINVERTEBRATE AND SMALLMOUTH BASS POPULATIONS IN FOUR STREAM BASINS IN SOUTHWESTERN WISCONSIN, 1987-90

Edited by David J. Graczyk

Surface-Water Hydrology and Quality
by David J. Graczyk

Macroinvertebrate Populations
by Richard A. Lillie[1] and Roger A. Schlesser[1]

Smallmouth Bass Populations
by John W. Mason[1], John D. Lyons[1], and Roger A. Kerr[1]

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 93-4024

Prepared in cooperation with the
WISCONSIN DEPARTMENT OF NATURAL RESOURCES

Madison, Wisconsin
1993

[1]Wisconsin Department of Natural Resources

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Robert M. Hirsch, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
6417 Normandy Lane
Madison, WI 53719

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Box 25286, MS 517
Denver Federal Center
Denver, Colorado 80225

CONTENTS

Page

CONTENTS--Continued

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

Page

TABLES--Continued

Page

CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

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
foot per mile (ft/mi)	0.1894	meter per kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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

$$°F = 1.8(°C) + 32$$

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). 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 1 milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

SURFACE-WATER HYDROLOGY AND QUALITY, AND MACROINVERTEBRATE AND SMALLMOUTH BASS POPULATIONS IN FOUR STREAM BASINS IN SOUTHWESTERN WISCONSIN, 1987-90

Edited by David J. Graczyk

ABSTRACT

Data on streamflow, water quality, and macroinvertebrate and smallmouth bass (*microptercus dolomieni*) populations were collected from July 1987 through September 1990, in four streams in southwestern Wisconsin to determine the effect of surface-water hydrology and quality on populations of macroinvertebrates and smallmouth bass. The study was a joint project of the U.S. Geological Survey and the Wisconsin Department of Natural Resources.

Drought conditions greatly affected streamflows in southwestern Wisconsin throughout much of the period of study. Precipitation in all four basins in 1988 and 1989 was 9.91 to12.41 inches less than 1951-80 normal precipitation of 32.88 inches.

The lowest annual mean discharge was recorded in water year 1988 at all of the streamflow-gaging stations except at Rattlesnake Creek, where annual mean discharge was lowest in water year 1990. Overland-flow runoff during the reproductive period of smallmouth bass (mid-May to mid-July) was 0.02 inch in 1988 at the Sinsinawa River and Rattlesnake Creek. Overland-flow runoff in the Little Platte River and the Livingston Branch of the Pecatonica River also was low in 1988 (0.03 inch and 0.04 inch, respectively) during the reproductive period of smallmouth bass. The trend of low overland-flow runoff continued in 1989; in water year 1990, however, overland-flow runoff during the reproductive period of smallmouth bass was 1.38 inches at Livingston Branch of the Pecatonica River and 0.22 inch at Rattlesnake Creek.

Turbidity ranged from 1.5 nephelometric turbidity units at Rattlesnake Creek to 3,700 nephelometric turbidity units at the Sinsinawa River. Suspended-solid concentrations ranged from 2 milligrams per liter at Rattlesnake Creek to a maximum 24,300 milligrams per liter at the Livingston Branch of the Pecatonica River. The high turbidities and suspended-solid concentrations, which occurred during storms, did not last for long periods of time and are not thought to have been harmful to the biota of the rivers.

Un-ionized ammonia concentrations exceeded the State of Wisconsin, Department of Natural Resources' standard of 0.04 milligram per liter for warmwater streams at all four of the streams. The maximum concentration of un-ionized ammonia measured was 0.10 milligram per liter at Rattlesnake Creek and there was no discernible effects on smallmouth bass or macroinvertebrates.

Dissolved-oxygen concentrations at all four study streams occasionally decreased to below or near the concentration of 1 milligram per liter considered necessary to sustain life of smallmouth bass. Two fish kills were documented as the result of low dissolved-oxygen concentrations. All of these episodes of low dissolved-oxygen concentrations occurred during or just after rainstorms and subsequent increasing streamflows.

Samples of water-sediment mixture and bottom material were analyzed for pesticides commonly used in the basins. Samples from all of the stations had concentrations of herbicides that exceeded the analytical reporting limit. Water-sediment samples at the Sinsinawa River had the highest herbicide concentration. The concentration of metolachlor was the highest of the herbicides--110 micrograms per liter; concentrations of atrazine and cyanazine were next highest at 97 and 84 micrograms per liter, respectively.

All of the water-sediment mixture samples had insecticide concentrations below the analytical reporting limit, with the exception of carbofuran. One water-sediment mixture sample collected at the Little Platte River had a carbofuran concentration of 0.44 microgram per liter. No pesticides were detected in the bottom-material samples collected at the four study streams.

Richness of macroinvertebrate taxa did not differ substantially among the four streams during the study, but the abundances of several taxa differed significantly among streams. Livingston Branch of the Pecatonica River had comparatively

few midges but many caddisflies, whereas Rattlesnake Creek had many non-insect taxa and relatively few caddisflies. The Little Platte River had consistently high numbers of caddisflies, mayflies, and riffle beetles.

Macroinvertebrate-community composition, as measured by Bray-Curtis dissimilarity coefficients, varied considerably over time within and among the streams. The macroinvertebrate-community composition of the Little Platte River changed very little during the winter of 1987-88 as compared to the other streams, but the community composition of the Livingston Branch of the Pecatonica River changed substantially. The communities of Rattlesnake Creek and Livingston Branch of the Pecatonica River became more similar to the community of the Little Platte River from fall 1987 through fall 1988, whereas the community in the Sinsinawa River remained distinct.

Water quality, as estimated by biotic-index values, generally was better in the Little Platte River than in the other streams from fall 1987 through fall 1988. However, water quality appeared to have deteriorated (biotic-index values increased) in the Little Platte River during the winter of 1988-89. Water quality in the Livingston Branch of the Pecatonica River also deteriorated during the same period.

The drought of 1988-89 and accompanying decrease in frequency of storms contributed to an uncharacteristically stable environment for macroinvertebrate development in most streams. Total taxa richness increased in three of the four streams. Total taxa richness did not increase in the Little Platte River, possibly because of moderate flooding that occurred prior to the spring 1989 sampling period or, more likely, because of changes in dissolved-oxygen concentrations. Although dissolved-oxygen concentrations were fairly similar in all streams, dissolved-oxygen concentrations were lower in 1989 in the Little Platte River than in other streams. The observed increase in biotic-index values in the Little Platte River during the spring of 1989 supports a decline in water quality.

Smallmouth bass reproduction was related to precipitation and streamflow during the critical mid-May to mid-July reproductive period. Reproductive success was good (38-297 Age 0 smallmouth bass per acre) in 1988 and 1989 and poor (0-3 Age 0 smallmouth bass per acre) in 1987 and 1990. This pattern corresponded with total precipitation of less than 7 inches in May and June in 1988 and 1989 and greater than 7 inches in 1989 and 1990.

In years when runoff exceeded 0.10 inch, only three or fewer Age 0 (smallmouth bass less than 1 year old) smallmouth bass per acre were caught in late summer to fall sampling surveys. In contrast, when overland runoff was less than 0.10 inch, 32 to 297 Age 0 smallmouth bass per acre were found in late summer or fall. The numbers of Age 0 smallmouth bass per acre were significantly different from each other at the 1-percent probability level (p=0.0001). Smallmouth bass reproductive success indicated that smallmouth bass in these streams were extremely vulnerable to the amount of runoff during the early stage of their life.

Low concentrations of dissolved oxygen constituted the most detrimental water-quality problem affecting smallmouth bass populations. Dissolved-oxygen concentrations were occasionally less than 3 milligrams per liter, a dissolved-oxygen concentration that may be detrimental to early-life stages of smallmouth bass in the streams; however, smallmouth bass were apparently able to withstand these low dissolved-oxygen concentrations and seem to have survived in some situations when dissolved-oxygen concentration decreased to1 milligram per liter.

INTRODUCTION

Streams in southwestern Wisconsin have historically been inhabited by smallmouth bass (*Micropterus dolomieui*). During the 1950's and 1960's, southwestern Wisconsin streams were renowned for their smallmouth bass fisheries (Ellis, 1968; Mathews, 1984). The counties of Grant, Iowa, and Lafayette (fig. 1) have more than 800 mi of streams that are classified by the Wisconsin Department of Natural Resources (WDNR) as smallmouth bass waters. These 800 mi represent about 25 percent of Wisconsin's total smallmouth bass stream length, and some of the southwestern streams are considered among the best smallmouth bass waters in the State.

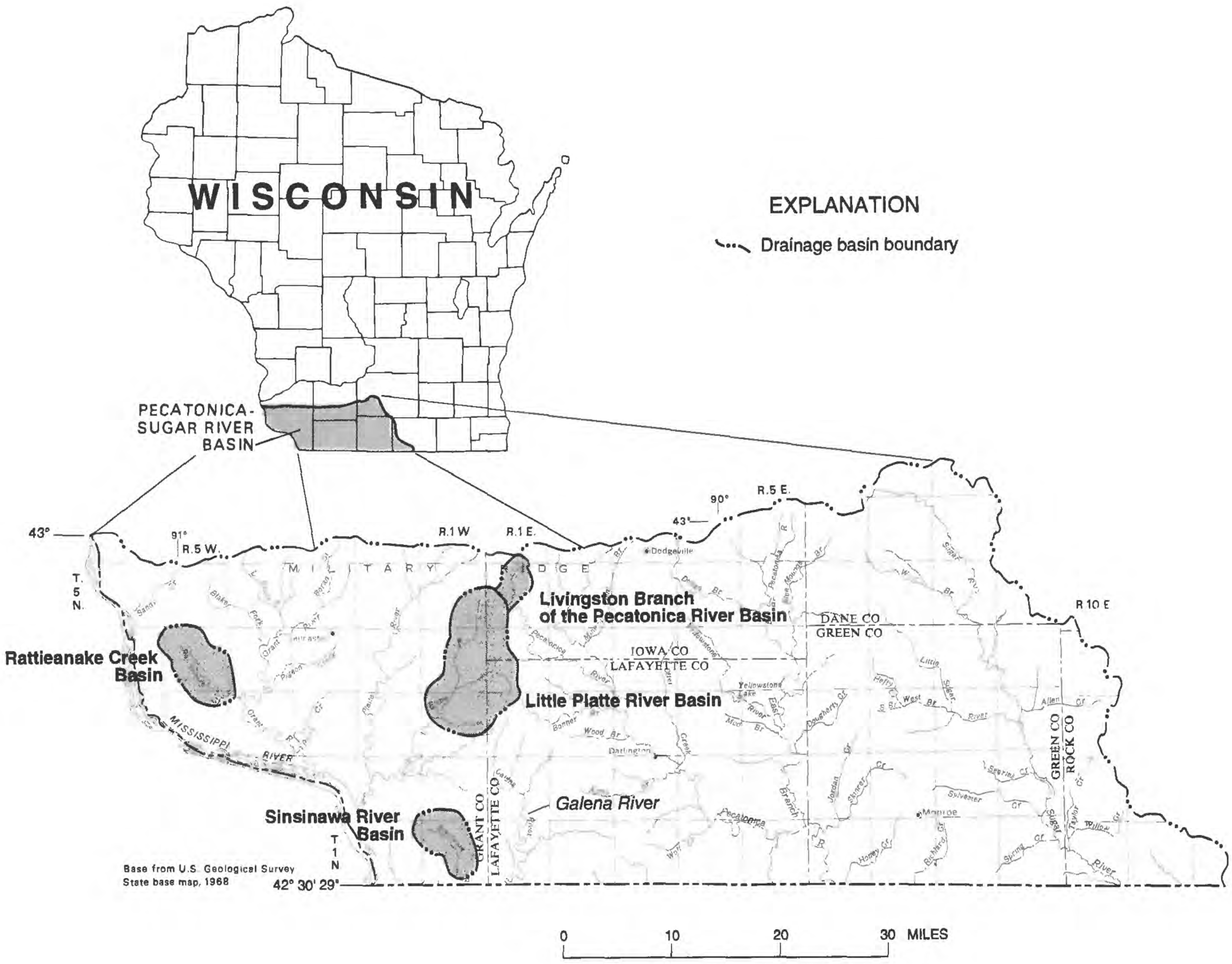

Figure 1. Location of study basins.

In the late 1970's, anglers and fisheries managers began reporting declines in smallmouth bass populations in the region's streams. In the early 1980's, some streams formerly noted for their smallmouth bass fishing had no remaining fishery. Investigations by Forbes (1985, 1989) and R.A. Kerr (Wisconsin Department of Natural Resources, written commun., 1985) provided preliminary information on the extent and magnitude of the situation. Many streams in the region seemed to be affected; only the Galena River in Lafayette County (fig. 1) was relatively unaffected and continued to support a fishable smallmouth bass population during the 1980's.

The WDNR established a working group to investigate the problem of declining smallmouth bass populations in the region and to identify research needs (Wisconsin Department of Natural Resources, 1985). Angler overexploitation and habitat deterioration were investigated as possible factors contributing to smallmouth bass population declines; however, Lyons and others (1988) observed that many streams with declining smallmouth bass populations still had good to excellent physical habitat, and Forbes (1989) concluded that angler over-exploitation was probably not the major cause of smallmouth bass population declines. The primary cause of the problem appeared to be changes in water quality that were detrimental to the fish--either reduced dissolved-oxygen concentrations, high un-ionized ammonia concentrations, high pesticide concentrations, or a combination of these factors.

In July 1987, a study was begun to determine the relation of streamflow and water quality to populations of macroinvertebrates and smallmouth bass in four streams in southwestern Wisconsin. The project was funded cooperatively by the U.S. Geological Survey (USGS) and the WDNR. Funding to WDNR, in part, was provided through Federal aid by the Sport Fish Restoration Act, Project F-83-R-23.

Purpose and Scope

This report presents results of a study to determine the relation of surface-water hydrology and quality to macroinvertebrate and smallmouth bass populations in four streams in southwestern Wisconsin from July 1987 through September 1990. The information presented in the report includes (1) surface-water hydrology, (2) surface-water quality, (3) macroinvertebrate populations, and (4) smallmouth bass populations. The four study streams were: (1) Rattlesnake Creek, (2) Livingston Branch of the Pecatonica River (Livingston Branch), (3) Sinsinawa River, and (4) Little Platte River (fig. 1).

Physical Setting

The smallmouth bass streams of southwestern Wisconsin are in the Driftless Area Ecoregion, an area that was not glaciated during the Pleistocene Epoch (Thwaites, 1963). The Driftless Area Ecoregion is characterized by plateaus that are deeply dissected by streams (Omernik and Gallant, 1988).

The undifferentiated dolomite and limestone of the Galena, Decorah, and Platteville Formations of Ordovician age is the predominant bedrock (Mudrey and others, 1982). This bedrock overlies the St. Peter Sandstone. The soils of the area are predominantly silt loams (Hole, 1976). Land use in the driftless area has been primarily agricultural since early settlement in the 1850's. Historically, small-scale livestock and dairy farming have been the major agricultural activities. Areas with the lowest slopes are used generally as cropland, whereas the steepest slopes and wet bottomlands have remained in permanent pasture and woodlots. Land-use changes in recent years, however, have resulted in an increase in the size of farms, more livestock feedlots, and increased cropland acreage, corn acreage in particular (Southwestern Wisconsin Regional Planning Commission, 1978). Land cover of the stream corridor (100 ft from each stream edge) differs among the streams but is mostly pasture and woodland (table 1). Overgrazing of some pastures has contributed to severe bank erosion in some locations. The bottom material in the four streams is predominantly cobbles and gravel with silt deposits in pools, except for Livingston Branch, which is mostly gravel with a large percentage of clay and silt (table 1).

Acknowledgments

The authors thank the landowners that allowed access to their properties for the sam-

Table 1. *Land-use and stream characteristics of the four study basins in southwestern Wisconsin*

[<, less than; >, greater than; ft, feet; mi^2, square mile; ft/mi, foot per mile; mm, millimeter]

Land-use or stream characteristic	Little Platte River	Livingston Branch of the Pecatonica River	Rattlesnake Creek	Sinsinawa River
Drainage area (mi^2)	79.7	16.4	42.4	24.9
Gradient (ft/mi)	12	21	16	22
Mean width (ft)	43	21	32	31
Bottom materials (percent)				
Cobble (>76 mm)	73	27	71	52
Gravel (<76 mm)	5	40	12	11
Clay-silt (<0.062 mm)	22	33	17	37
Corridor land cover[1] (percent)				
Grassland	17	86	33	64
Cropland	23	1	24	11
Woodland	55	12	43	24
Other	5	1	0	1

[1]Measured approximately 100 ft from each stream edge.

pling of macroinvertebrates and smallmouth bass. Special thanks are extended to the landowners who allowed gaging stations on their property: Dan Kitto (Rattlesnake Creek), Roger Runde (Sinsinawa River), Skip and Fay Stone (Little Platte River), and Mary Johnson (Livingston Branch). Without their cooperation, the authors would not have been able to collect the necessary data to complete the study. The authors also thank Gerald Wegner, Gregory Quinn, Brian Dhuey, and Irene Olson of the Wisconsin Department of Natural Resources for assisting in the fish- and macroinvertebrate-population surveys.

DATA-COLLECTION NETWORK AND METHODS

In three of the four study streams--Livingston Branch, Rattlesnake Creek, and the Sinsinawa River--smallmouth bass populations were believed to have declined. The Little Platte River was believed to have a relatively stable smallmouth bass population and to be generally unaffected by water-quality problems.

Gaging stations equipped to continuously monitor streamflow, water temperature, dissolved oxygen, and precipitation were installed in July 1987 at Rattlesnake Creek, Livingston Branch, the Sinsinawa River, and the Little Platte River (figs. 2-5). Discharge and water temperature were continuously recorded throughout the year, and dissolved-oxygen concentration and precipitation were monitored during the open-water period, typically March 1 through November 30 each year. Measurements of streamflow were made by use of standard gaging methods (Rantz and others, 1982). Each gaging station was equipped with mercury-manometer water-level recording equipment; gage height was recorded every 15 minutes. Discharge measurements were made every 4 to 6 weeks, and more often during high flow, to define a stage-discharge relation for each site. Water-temperature measurements were made at 15-minute intervals at each station by use of an automatic recorder and a submerged temperature probe.

Dissolved-oxygen concentration was recorded every 15 minutes by a fixed-in-place dissolved-oxygen probe with a semipermeable membrane and a dissolved-oxygen meter. The monitoring sites were visited every 7 to 10 days. As part of these visits, a portable dissolved-oxy-

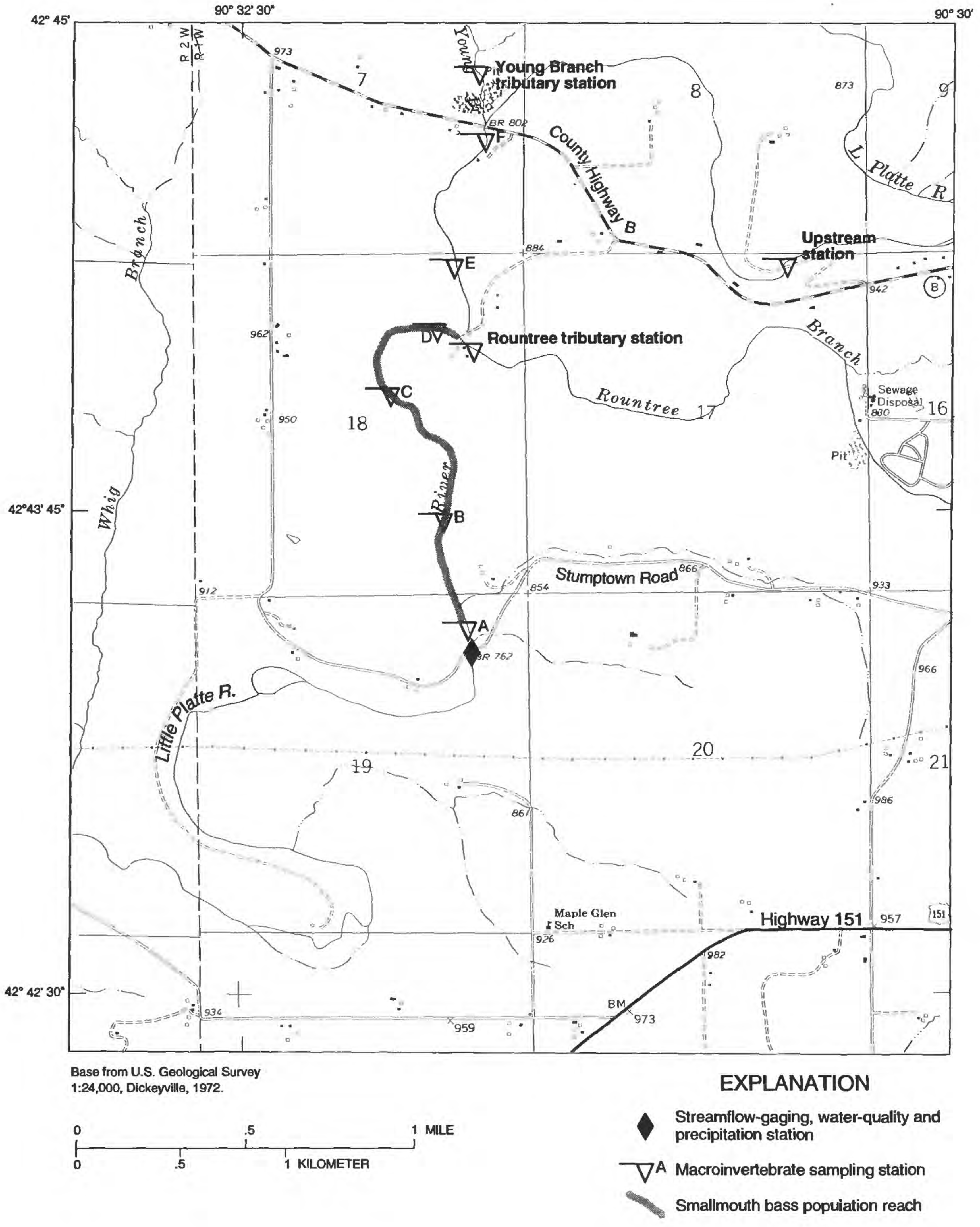

Figure 2. Location of the Little Platte River data-collection sites.

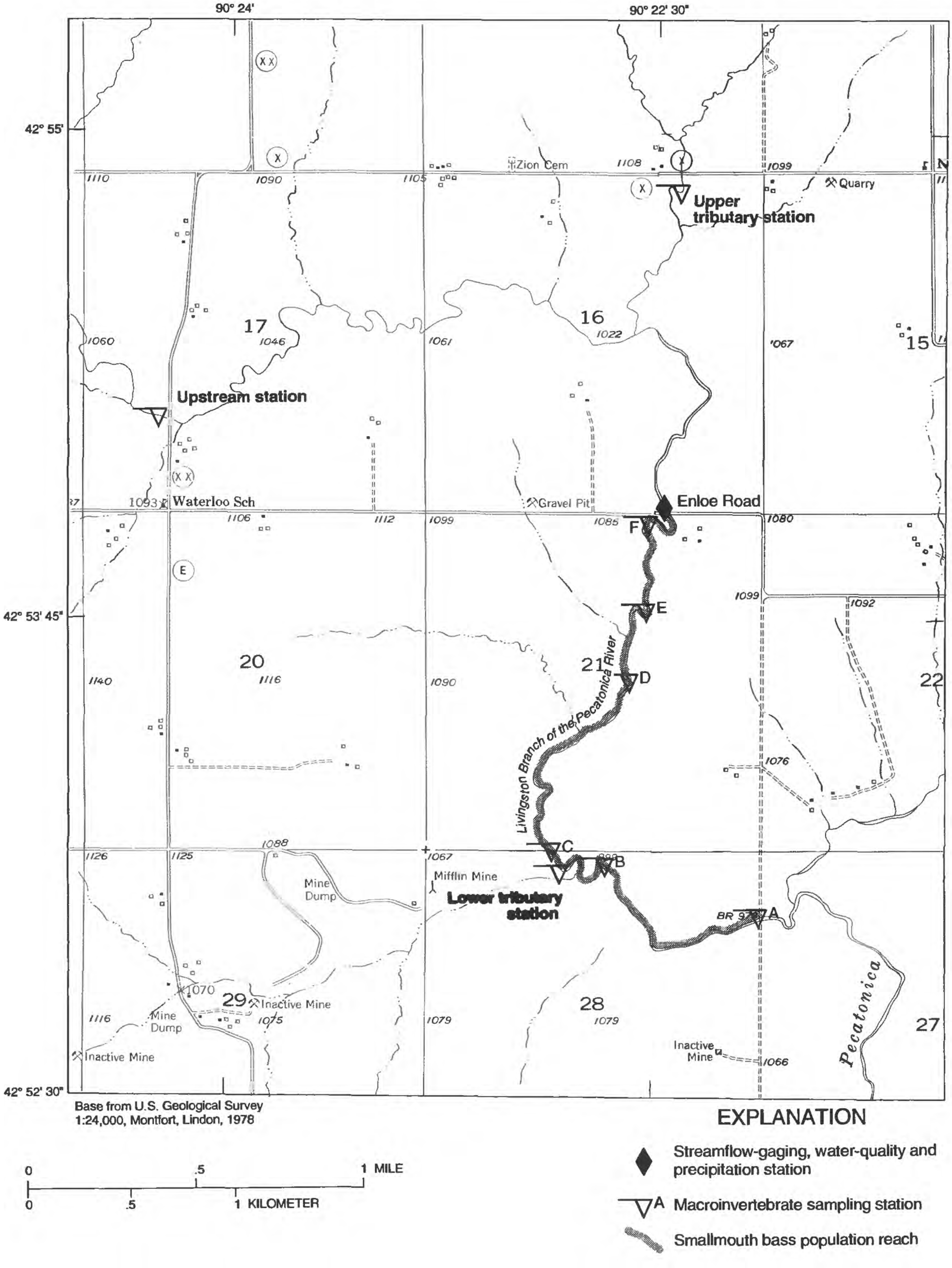

Figure 3. Location of Livingston Branch of the Pecatonica River data-collection sites.

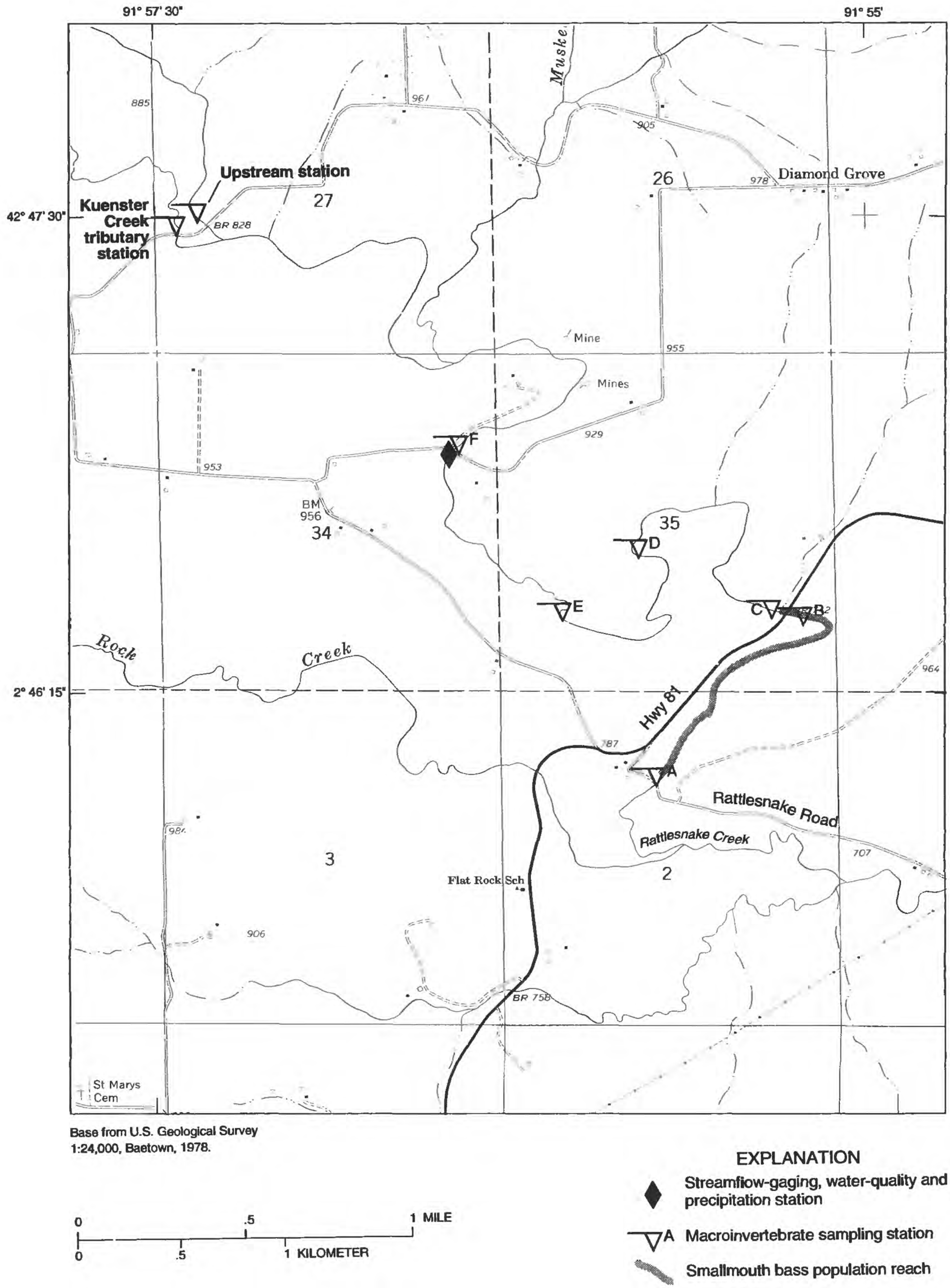

Figure 4. Location of Rattlesnake Creek data-collection sites.

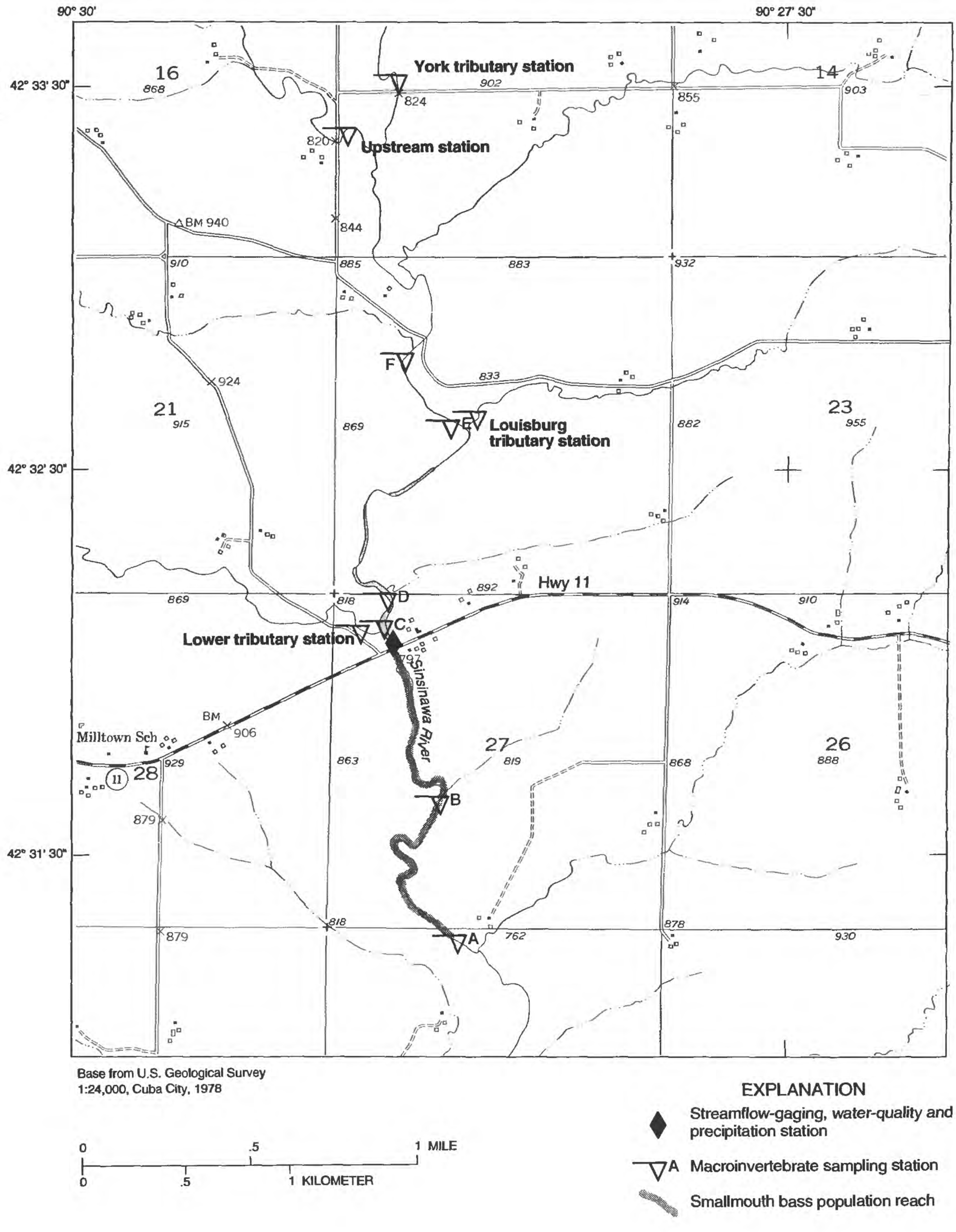

Figure 5. Location of Sinsinawa River data-collection sites.

gen meter was calibrated by use of the Winkler titration method and then used to calibrate the fixed-in-place dissolved-oxygen meters. The membranes of the fixed-in-place dissolved-oxygen probes were inspected for wrinkles and tears and were replaced if defects were found. Undamaged membranes were cleaned with a concentrated bleach solution, rinsed with stream water, and were replaced in the stream. The fixed-in-place meters were then calibrated to record the stream-water dissolved-oxygen concentrations indicated by the portable meter. Corrections were made to the raw data collected between meter calibrations by linearly adjusting values on a percentage basis.

Each gaging station was equipped with a stage-activated refrigerated water sampler for collecting water-sediment mixture samples that were analyzed for turbidity, suspended solids, ammonia nitrogen, and pH. Samples collected were selected for analysis to represent variation in water quality over the hydrograph.

A refrigerated water-quality sampler was installed at each of the four sites in May 1988 to collect samples subsequently analyzed for pesticides. These samplers had Teflon[1]-lined sampler tubing and glass bottles. The samplers were stage activated. The water-sediment mixture samples were analyzed for nine agricultural herbicides and insecticides (carbofuran, phorate, terbufos, atrazine, alachlor, metolachlor, cyanazine, fonofos, and chlorpyrifos) most commonly used in southwestern Wisconsin (Wisconsin Department of Agriculture, Trade, and Consumer Protection, 1985).

Water-quality samples were collected during base-flow periods (periods of no or very little overland flow) with hand-held samplers by width and depth integration of the stream. The base-flow samples were analyzed for the same constituents as the samples taken by the water-quality samplers and were also analyzed for nitrate plus nitrite nitrogen and total phosphorus.

Precipitation was recorded during ice-free periods, usually March 1 through November 30, at all four of the gaging stations. Precipitation was collected in an 8-in. collector, which drained into a 3-in.-inside-diameter standpipe. Precipitation measurements were made every 15 minutes, and daily totals were reported. Data were supplemented with weather records obtained from the National Weather Service at the University of Wisconsin Experimental Farm near Lancaster, Wis. (U.S. Department of Commerce, 1987, 1988, 1989, 1990).

Macroinvertebrates were sampled at six stations (A through F, in order from downstream to upstream) on each river (figs. 2-5). Length of macroinvertebrate-sampling reaches ranged from 1.9 mi to 3.3 mi. Placement of each macroinvertebrate station was based on the need to determine spatial distribution patterns. Several tributary sites also were sampled, and one additional site was sampled upstream from the main study reach in each river to determine if there were any spatial differences in macroinvertebrates.

Macroinvertebrate samples were collected by personnel of the Water Resources Research (WRR) section of the WDNR from riffle areas in the study reaches during fall 1987, spring 1988, and fall 1989, with a standard D-frame kick net equipped with 0.6-mm mesh netting. The macroinvertebrate samples were used to calculate a qualitative biotic-index (BI) value. The biotic index is a system for measuring average pollution tolerance of a random subsample of organisms inhabiting riffles (Hilsenhoff, 1987). Additional BI samples and data were collected each spring and fall near the streamflow-monitoring stations by personnel of the WDNR Dodgeville area office. Sampling methodology followed that recommended by Hilsenhoff (1987, 1988).

Macroinvertebrate samples for quantitative analysis were collected by WRR personnel from riffle areas in the study reaches during the spring of 1988 and fall of 1987-89 by use of a 0.086-m^2 Hess stovepipe-stream sampler equipped with a 0.5-mm mesh net (Merritt and Cummins, 1984). Macroinvertebrates attached to the surfaces of rocks and wood confined within the sampler were handpicked, but no attempt was made to recover deeply embedded organisms.

---

[1]Use of brand, firm, and trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Samples were preserved in 95 percent ethanol and returned to the laboratory for identification. Organisms collected in the Hess sampler were identified to order or family level, and the organisms in the kicknet sampler were identified to genus or species level (Hilsenhoff, 1987). The macroinvertebrate samples collected by the WDNR Dodgeville area office were processed and identified by the University of Wisconsin-Stevens Point. Various taxonomic keys for taxa resident to Wisconsin streams were used (references are available from the authors upon request).

Macroinvertebrate taxa collected in the Hess samples were categorized into one of five function-feeding classes--scraper, shredder, predator, filter feeder, or collector/gather--on the basis of criteria listed by Merritt and Cummins (1984).

Smallmouth bass population surveys were done on river reaches in proximity to the streamflow and water-quality monitoring stations (figs. 2-5). Length of the reaches ranged from 0.85 mi on Rattlesnake Creek to 2.56 mi on Livingston Branch of the Pecatonica River.

Smallmouth bass populations were sampled in late summer each year during 1987 through 1990, in spring 1988 and 1989, and on a few other occasions. Standard WDNR wading electrofishing gear--a 250-volt DC unit towed by two or three electrode-carrying operators--was used in estimating smallmouth bass population characteristics. Relative abundance of smallmouth bass and size and age-class distributions were determined by making one upstream shocker run through the study reaches. Blocknets (nets stretched horizontally across the stream to limit fish movement) were not used to isolate survey reaches during sampling. Double-run, mark, and recapture surveys were made in late summer 1988. Two upstream shocker runs in consecutive days were made on all of the streams. On the first shocker run, all fish captured were counted and marked by clipping a fin and returned to the stream near where the fish were captured. The next day, another upstream shocker run was made and all fish captured were counted both marked and unmarked fish. The ratio of marked fish on the first run times the total fish captured on the second run divided by the marked fish captured on the second run is an estimate of the total population (Lackey and Hubert, 1978). Analyses of smallmouth bass populations are based on data making one upstream shocker run only; these data constitute a reliable index of relative populations and population changes, but they do not reflect total populations inhabiting the study reaches. One-run capture efficiencies (the percentage of the estimated total population sampled during one shocker run) in late summer 1988 showed that capture efficiencies were positively related to smallmouth bass age class and negatively related to stream size. The percentage of the estimated total population sampled during one shocker run in 1988 and mean width (in feet) of river sampled are listed in the table below; "--" indicates data not collected.

All smallmouth bass captured were measured, weighed, and assigned to age groups by scale reading or length-frequency distribution. In spring 1989, smallmouth bass longer than 6 in. were tagged to determine their movement.

Age group[1]	Little Platte River	Livingston Branch of the Pecatonica River	Rattlesnake Creek	Sinsinawa River
0	10	38	20	27
I	42	--	50	--
II-IV$^+$	63	--	80	82
Mean width	43	21	32	31

[1]Age 0 - Smallmouth bass less than 1 year old.
Age I - Smallmouth bass 1 year old but less than 2 years old.
Age II - IV$^+$- Smallmouth bass 2 years old to less than 5 years old.

Literature information and WDNR file data were used wherever possible to show bass population trends for a time period greater than that of this study. Additional information on smallmouth bass--including age, growth, and weight data--was compiled but not included in this report. This additional information is available from the authors upon request.

SURFACE-WATER HYDROLOGY AND QUALITY

by David J. Graczyk[2]

Hydrology

A relation between the abundance of young-of-the-year smallmouth bass--that is, those produced in a given year--and the total precipitation in the respective drainage basins in May and June was observed in streams in northeastern Iowa by Cleary (1956). When total precipitation in May and June combined was less than 7 in., reproductive success and subsequent survival of young-of-the-year was good. If precipitation exceeded 7 in., reproductive success and subsequent survival of young-of-the-year was poor.

Combined precipitation of May and June, 1987-90, for the four study streams in southwestern Wisconsin is listed in table 2. During 1987 and 1990, combined precipitation for May and June at the University of Wisconsin Experimental Farm near Lancaster, Wis. was greater than 7 in. Precipitation in 1990 was well above the 1951-80 average of 7.94 in.; June precipitation alone at Livingston Branch was 9.29 in. During one storm on June 29, 5.25 in. was recorded before the rain-gage standpipe became full and overflowed; 7.25 in. of rain was recorded at the National Weather Service rain gage at Darlington, Wis., approximately 20 mi southwest of the gage.

[2]U.S. Geological Survey, 6417 Normandy Lane, Madison, Wis. 53719.

A severe drought occurred in southwestern Wisconsin and the upper Midwest in 1988 and 1989. Average annual precipitation for 1951-80 at the Lancaster precipitation gage is 32.88 in. During 1988 and 1989, annual precipitation measured at the streamflow-gaging stations was 9 to 12 in. below the 1951-80 average. Total precipitation in May and June 1988 ranged from 6.00 to 6.76 in. below the 1951-80 average of 7.94 in. measured at the gaging station. In May through June 1989, combined precipitation ranged from 3.63 to 4.78 in. below the 1951-80 normal precipitation measured at the gaging station.

The effects of watershed runoff on smallmouth bass population also were noted by Cleary (1956). High streamflow during the May-June period could disperse eggs or sweep Age 0 smallmouth bass from nursery habitat and greatly reduce Age 0 smallmouth bass survival. Mason and others (1991) confirmed Cleary's results that when stream discharge was below normal, abundant smallmouth bass were produced. A critical period for smallmouth bass reproductive success is from mid-May through mid-July (May 15 through July 15); hereafter in this report, the term "critical period" refers to that time period (Becker, 1983).

Table 2. *Precipitation in May and June at the rain gages in the study basins in southwestern Wisconsin, 1987-90*

[units in inches]

Study site	1987			1988			1989			1990		
	May[1]	June[1]	Total	May	June	Total	May	June	Total	May	June	Total
Little Platte River	[2]3.55	[2]4.13	[2]7.68	0.75	0.55	1.30	1.79	1.37	3.16	[2]4.83	[2]5.48	[2]10.31
Livingston Branch of the Pecatonica River	[2]3.55	[2]4.13	[2]7.68	.75	.43	1.18	2.27	1.57	3.84	3.90	9.29	13.19
Rattlesnake Creek	[2]3.55	[2]4.13	[2]7.68	1.30	.29	1.59	1.74	2.57	4.31	5.76	5.04	10.80
Sinsinawa River	[2]3.55	[2]4.13	[2]7.68	1.05	.39	1.44	1.89	2.00	3.89	3.13	[3]5.48	[3]8.61

[1] Precipitation data from University of Wisconsin Experimental Farm near Lancaster. Precipitation collectors at the streamflow-gaging stations were not in operation until late June or early July.
[2] Precipitation data from University of Wisconsin Experimental Farm near Lancaster. Precipitation collector was not in operation.
[3] Precipitation data collected only until June 26.

Streamflow data collected as part of this study were used to determine the streamflow characteristics summarized in table 3. Data were collected during only part of water year[2] 1987 at all of the sites. In water year 1990 data were not collected from July through September at the Little Platte and Sinsinawa Rivers. Thus, most streamflow characteristics were not calculated for those years. All streamflow data collected can be found in USGS annual water-resources data reports for Wisconsin (Holmstrom and others, 1987, 1988, 1989, 1990).

The lowest annual mean discharge was recorded in the 1989 water year at all of the sites except for Rattlesnake Creek, where the lowest annual mean discharge was recorded in water year 1990 (table 3). Annual mean discharges in 1989 were lower than those in 1988 except for Rattlesnake Creek because of below average precipitation in 1988 and 1989. The annual mean discharge at Livingston Branch also might have been low in 1990 if not for a large storm in late June. A maximum peak discharge for the period of record, 6,260 ft^3/s, was recorded on June 29, 1990. The recurrence interval of this discharge exceeded 100 years. The 100-year discharge calculated by use of regression equations is 3,200 ft^3/s (Krug and others, 1992). The overland-flow runoff at the Livingston Branch was 2.63 in. in 1990 as compared to 0.89 and 1.27 in. in 1988 and 1989, respectively. This unusually high amount of overland-flow runoff may account for the high annual mean discharge at Livingston Branch in 1990 as compared to other years; at Rattlesnake Creek, overland-flow runoff was 1.12 in. in 1990, 1.08 in. in 1988, and 1.34 in. in 1989.

Another streamflow characteristic for determining smallmouth bass reproductive success may be runoff during the critical period. Streamflow may be separated into two parts: overland-flow runoff and base-flow runoff. Overland-flow runoff is water that flows upon the ground and flows into streams, whereas base-flow runoff is water that percolates down through the soil until it reaches the water table and eventually discharges to the stream (Linsley and others, 1975). Years with low overland-flow runoff during the critical reproductive period for smallmouth bass will usually result in good reproductive success.

In 1988, overland-flow runoff during the critical reproductive period was lowest (0.02 in.) at the Sinsinawa River and Rattlesnake Creek (table 3). Overland-flow runoff at the Little Platte River and Livingston Branch sites also was very low during the critical period in 1988 (0.03 in. and 0.04 in.; table 3). In 1989, the trend of low overland-flow runoff during the critical period continued. Southwestern Wisconsin was still in a drought, and streamflow responded to below-normal precipitation. Overland-flow runoff during the critical period was highest at Livingston Branch at 1.38 in. in 1990 (70 percent of total runoff) (table 3). At Rattlesnake Creek, overland-flow runoff during the critical period was 0.22 in. (29 percent of total runoff) in 1990 (table 3). Data collection at the Little Platte River and the Sinsinawa River was discontinued in June 1990.

Water-level changes also can indicate if streamflow conditions are conducive to good reproductive success (Cleary, 1956). Small stream-stage changes before the reproductive period may be beneficial, but rises that cause extensive scouring of the stream bottom during the nesting period may be detrimental (Pflieger, 1975). If the stream-stage rises are large enough to cause scouring of the stream bottom, reproductive success may be poor. The numbers of times the stream stages rose greater than 0.5 ft during the critical period from 1987 through 1990 are summarized in table 4.

During the 1990 critical period, stream-stage rises of greater than 0.5 ft were recorded at all of the sites (table 4). On Rattlesnake Creek, stream-stage rises were between 0.5 ft and 1.0 ft on 3 days and greater than 1.0 ft on 1 day. On Livingston Branch, the stream stage rose more than 1.0 ft on 2 days. On June 29, 1990, the stream stage rose more than 10 ft and spilled into the overbank. Overflow from this storm probably trapped newly-hatched smallmouth bass. Moreover, with the increasing discharge, the stream velocity increased. The increased velocity may have scoured the stream

[2]Water year. In U.S. Geological Survey reports dealing with surface-water supply, the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ended September 30, 1987, is called the "1987 water year."

Table 3. *Summary of streamflow characteristics of the study streams in southwestern Wisconsin, water years 1987-90*

[--, not determined]

Streamflow characteristic	Water year[1] 1987	1988	1989	1990
Little Platte River				
Annual mean discharge, in cubic feet per second	--	37.3	26.5	--
Runoff, in inches	--	6.35	4.51	--
Overland-flow runoff, in inches	--	.74	1.49	--
Base-flow runoff, in inches	--	5.61	3.12	--
Runoff for critical period[2], in inches	--	.82	.44	--
Overland-flow runoff for critical period, in inches	--	.03	.05	--
Base-flow runoff for critical period, in inches	--	.79	.39	--
Maximum recorded peak discharge, in cubic feet per second	175	472	2,970	3,800
Livingston Branch of the Pecatonica River				
Annual mean discharge, in cubic feet per second	--	11.1	5.93	7.20
Runoff, in inches	--	9.19	4.93	5.96
Overland-flow runoff, in inches	--	.89	1.27	2.63
Base-flow runoff, in inches	--	8.30	3.66	3.33
Runoff for critical period[2], in inches	--	1.14	.40	2.01
Overland-flow runoff for critical period, in inches	--	.04	.02	1.38
Base-flow runoff for critical period, in inches	--	1.10	.38	.63
Maximum recorded peak discharge, in cubic feet per second	108	203	602	6,260
Rattlesnake Creek				
Annual mean discharge, in cubic feet per second	--	19.2	14.5	11.9
Runoff, in inches	--	6.13	4.64	3.80
Overland-flow runoff, in inches	--	1.08	1.34	1.12
Base-flow runoff, in inches	--	5.05	3.30	2.68
Runoff for critical period[2], in inches	--	.68	.54	.75
Overland-flow runoff for critical period, in inches	--	.02	.05	.22
Base-flow runoff for critical period, in inches	--	.66	.49	.53
Maximum recorded peak discharge, in cubic feet per second	1,130	445	825	210

Table 3. *Summary of streamflow characteristics of the study streams in southwestern Wisconsin, water years 1987-90*--Continued

Streamflow characteristic	Water year[1] 1987	1988	1989	1990
	Sinsinawa River			
Annual mean discharge, in cubic feet per second	--	11.9	9.30	--
Runoff, in inches	--	6.48	5.07	--
Overland-flow runoff, in inches	--	.58	1.01	--
Base-flow runoff, in inches	--	5.90	4.06	--
Runoff for critical period[2], in inches	--	.92	.57	--
Overland-flow runoff for critical period, in inches	--	.02	.03	--
Base-flow runoff for critical period, in inches	--	.90	.54	--
Maximum recorded peak discharge, in cubic feet per second	61	187	1,270	334

[1] Water year. In U.S. Geological Survey reports dealing with surface-water supply, the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ended September 30, 1987, is called the "1987 water year."
[2] Critical period is May 15 through July 15.

bottom and disrupted the smallmouth bass nests. The Little Platte River also rose by more than 0.5 ft. on several days during the critical reproductive period. During the storm on June 29, the stream stage rose by more than 7 ft. Like Livingston Branch, the Little Platte River spilled into the overbank area, and the overflow could have trapped adult and juvenile smallmouth bass.

Water Quality

Smallmouth bass populations can be adversely affected by inorganic and organic chemicals from nonpoint-source runoff. Water-quality data collected at the four streamflow-gaging stations were used to determine the effects of water quality on smallmouth bass and macroinvertebrate populations. All water-quality data collected as part of this study are published in USGS annual water-resources data reports for Wisconsin (Holmstrom and others, 1987, 1988, 1989, 1990).

Turbidity and Suspended Solids

Smallmouth bass populations can be adversely affected by high turbidities and the associated high suspended- solids concentrations in two ways: (1) mechanical injury or clogging of gills, and (2) reduction of light penetration, which can reduce primary productivity and the food supply for juvenile smallmouth bass and other fish species (Bulkley, 1975).

Maximum turbidity ranged from 80 NTU in 1987 at the Little Platte River to 3,700 NTU in 1990 at the Sinsinawa River (table 5). These maximum values were measured during storms, and these maximum values did not last for long periods of time.

Minimum turbidities ranged from 1.5 NTU at Rattlesnake Creek in 1990 to 28 NTU at Livingston Branch in 1987 (table 5). The minimum turbidities are representative of periods when streamflows were low and (or) overland flow was nonexistent. These low-flow periods are indica-

Table 4. *Stream-stage rises during the critical reproductive period, mid-May through mid-July, 1987-90*

[≥, greater than or equal to; ≤, less than or equal to; ft, foot]

Stream rise	[1]1987	1988	1989	[2]1990
		Little Platte River		
≥0.5 ft but ≤0.99 ft	0	0	0	2
≥1.0 ft but ≤1.99 ft	0	0	0	1
≥2.0 ft	0	0	0	1
		Livingston Branch of the Pecatonica River		
≥0.5 ft but ≤0.99 ft	0	0	0	0
≥1.0 ft but ≤1.99 ft	0	0	0	1
≥2.0 ft	0	0	0	1
		Rattlesnake Creek		
≥0.5 ft but ≤0.99 ft	0	0	0	3
≥1.0 ft but ≤1.99 ft	0	0	0	1
≥2.0 ft	1	0	0	0
		Sinsinawa River		
≥0.5 ft but ≤0.99 ft	0	0	0	1
≥1.0 ft but ≤1.99 ft	0	0	0	1
≥2.0 ft	0	0	0	0

[1] Data collection started on June 4 at Rattlesnake Creek, June 19 at Livingston Branch of the Pecatonica River, June 10 at Little Platte River, and June 23 at Sinsinawa River.
[2] Data collection ended on June 22 at Little Platte River and on June 26 at Sinsinawa River.

tive of normal flow conditions throughout the year.

General standards for suspended-solids concentrations (Alabaster and Lloyd, 1982) include the following: (1) waters with suspended-solids concentrations less than 25 mg/L would have no harmful effects on fish populations, (2) waters with suspended-solids concentrations from 25 to 80 mg/L should be able to maintain good populations of fish,(3) waters with suspended-solids concentrations from 80 to 400 mg/L are unlikely to maintain good populations of fish, and (4) waters with suspended-solids concentrations greater than 400 mg/L can maintain only poor fisheries. Suspended-solids concentrations greater than several thousand milligrams per liter may not kill fish even though those concentrations may be maintained for hours or days, but good fisheries may not be maintained (Alabaster and Lloyd, 1982).

Suspended-solids concentrations were high on the Livingston Branch in 1989; maximum concentration was 24,000 mg/L. In the Little Platte River, the maximum suspended-solids concentration was 15,000 mg/L in 1989. A maximum suspended-solids concentration of 4,800 mg/L was measured in 1989 at Rattlesnake Creek, and a maximum of 6,400 mg/L was measured at the Sinsinawa River in 1990. The maximum suspended-solids concentrations

Table 5. *Statistical summary of selected water-quality data for the study streams, 1987-90*

[units in milligrams per liter unless specified otherwise; pH, in units; turbidity in nephelometric turbidity units; --, no data available; <, less than; Max, maximum; Min, minimum]

Water-quality property or constituent	Water year 1987				Water year 1988				Water year 1989				Water year 1990			
	Sample size	Max	Min	Median	Sample size	Max	Min	Median	Sample size	Max	Min	Median	Sample size	Max	Min	Median
Little Platte River																
Turbidity	10	80	5.6	66	33	350	3	61	32	2,400	2	190	34	860	2.6	200
pH	10	8.1	7.2	7.6	33	8.7	7.5	7.9	35	8.7	7.3	7.7	34	8.3	7.2	7.9
Dissolved ammonia nitrogen, as N	10	.59	.04	.11	34	1.9	<0.02	.84	35	4.2	<0.02	2.3	34	3.10	.04	1.50
Dissolved nitrate and nitrite nitrogen, as N	5	4.4	2.7	--	3	7.6	5.17	--	4	4.5	2.8	--	1	5.7	--	--
Suspended solids	10	1,100	73	280	33	3,200	11	316	35	15,000	3	660	34	5,100	6	910
Total phosphorus	--	--	--	--	2	3	.30	--	3	.39	.33	--	1	.77	--	--
Livingston Branch of the Pecatonica River																
Turbidity	19	89	28	80	31	730	9.5	82	36	3,000	3	340	28	2,100	5.8	260
pH	19	8	7	7.5	31	8.3	7.4	7.9	36	8.5	7	7.4	27	8.1	7	7.5
Dissolved ammonia nitrogen, as N	20	2.3	.16	1.04	31	4.2	.02	1.8	36	6.8	.02	4.3	28	5.2	.10	2.65
Dissolved nitrate and nitrite nitrogen, as N	9	7.4	3.1	4.8	3	11.8	.07	--	4	10	4.1	--	1	8.3	--	--
Suspended solids	19	5,000	230	1,200	31	9,100	28	690	36	24,400	9	2,700	28	8,900	18	2,000
Total phosphorus	--	--	--	--	2	.650	.220	--	3	.18	.07	--	1	.16	--	--

Table 5. *Statistical summary of selected water-quality data for the study streams, 1987-90*--Continued

Water-quality property or constituent	Water year 1987				Water year 1988				Water year 1989				Water year 1990			
	Sample size	Max	Min	Median	Sample size	Max	Min	Median	Sample size	Max	Min	Median	Sample size	Max	Min	Median
Rattlesnake Creek																
Turbidity	17	170	15	80	16	120	2.7	31.5	37	560	1.7	110	19	400	1.5	120
pH	16	8.2	7.3	7.8	16	8.4	7.5	8.1	37	8.3	6.9	7.6	26	8.4	7.1	8
Dissolved ammonia nitrogen, as N	18	4.1	.05	1.1	16	2.3	.02	.395	37	5.2	.02	3.1	26	4.4	<.10	1.8
Dissolved nitrate and nitrite nitrogen, as N	9	3.1	2.1	2.4	3	6.4	3.5	--	14	4.7	1.55	2.02	28	4.7	.90	2.7
Suspended solids	16	920	38	390	16	440	7	150	37	4,800	5	430	28	3,500	2	590
Total phosphorus	--	--	--	--	2	.20	.110	--	10	4.03	.06	1.53	27	4.04	.07	1.73

Water-quality property or constituent	Water year 1987				Water year 1988				Water year 1989				Water year 1990			
	Sample size	Max	Min	Median	Sample size	Max	Min	Median	Sample size	Max	Min	Median	Sample size	Max	Min	Median
Sinsinawa River																
Turbidity	8	140	6.5	77	28	500	5.6	44	18	360	3	90	18	3,700	4.6	310
pH	8	8	7.1	7.7	28	8.3	7.3	7.9	18	8.3	7.3	7.8	18	8.2	7	7.5
Dissolved ammonia nitrogen, as N	8	1	.08	.375	28	2.9	.04	1.5	18	4.2	.04	3.1	18	4.1	.04	2.3
Dissolved nitrate and nitrite nitrogen, as N	4	5	4	--	3	6.3	4.6	--	4	5.8	2.7	--	1	5.2	--	--
Suspended solids	8	530	78	330	28	3,000	15	280	18	2,100	10	230	18	6,400	16	1,400
Total phosphorus	--	--	--	--	2	.12	.10	--	3	.10	.08	--	1	.07	--	--

measured were all greater than the 400 mg/L standard for maintenance of poor fisheries at the sites for the years studied. As with turbidity, high suspended-solids concentrations occurred during storms and may not have lasted for long periods of time. High suspended-solids concentrations are not uncommon in surface waters in the southwestern part of Wisconsin. Suspended-sediment concentrations and suspended-sediment yields are typically high in this part of the state (Hindall, 1976), in part because of the prevalence of silty soils and very steep slopes.

Minimum concentrations of suspended solids ranged from 2 mg/L in 1990 at Rattlesnake Creek to 230 mg/L at the Livingston Branch of the Pecatonica River in 1987. The minimum concentration of suspended solids may be more indicative of normal flows than maximum concentrations. Most of the minimum concentrations were measured during low-flow periods; that is, periods of little or no overland flow. The minimum concentrations of suspended solids were below the 25 mg/L standard where there would be no harmful effects on fish populations except at all the sites in 1987 and at Livingston Branch in 1988. In 1987, the number of significant storms was greater and periods of nonrunoff were fewer than in 1988, 1989, and 1990.

Ammonia Nitrogen

Ammonia nitrogen (NH_4^+) in itself is not harmful to fish or macroinvertebrates. The harmful effects of ammonia nitrogen are from its un-ionized fraction (NH_3), which is toxic to fish and macroinvertebrates. The un-ionized fraction increases as pH and temperature increase. Un-ionized nitrogen at concentrations of 1.2 to 1.8 mg/L have been found to have toxic effects on smallmouth bass (Broderius and others, 1985).

Samples from all sites had concentrations of un-ionized ammonia greater than 0.04 mg/L (table 6), the State of Wisconsin standard for warmwater streams (O.H. Schuettpelz and T.H. Harpt, Wisconsin Department of Natural Resources, written commun., 1980). Seven samples with concentrations greater than 0.04 mg/L were collected from Rattlesnake Creek and the Little Platte River. The maximum concentration of un-ionized ammonia measured was 0.10 mg/L at Rattlesnake Creek in July 1987. This is well below the reported toxic level of 1.2 to 1.8 mg/L of un-ionized ammonia (Broderius and others, 1985). It has been reported that un-ionized ammonia and dissolved oxygen have a synergistic relationship (Downing and Merkens, 1955); that is, as dissolved-oxygen concentration decreases, the concentration of un-ionized ammonia that is toxic to fish also decreases. During a storm in July 1987, the measured dissolved-oxygen concentration was less than 0.1 mg/L. A fish kill during and after this storm was reported. The cause of the fish kill was attributed to low-dissolved oxygen concentration, but the high concentrations of un-ionized ammonia also may have stressed the smallmouth bass and contributed to the fish kill. At the other two sites, concentrations were slightly greater than or equal to 0.04 mg/L of un-ionized ammonia during the study.

Table 6. *Number of water-sediment samples in which concentrations of un-ionized ammonia were greater than or equal to 0.04 milligram per liter*

Study site (sample size[1])	Number of samples with un-ionized ammonia greater than or equal to 0.04 milligram per liter			
	1987	1988	1989	1990
Little Platte River (104)	0	1	0	6
Livingston Branch of the Pecatonica River (104)	3	0	0	1
Rattlesnake Creek (87)	6	1	0	0
Sinsinawa River (74)	0	0	0	1

[1] Sample size is the number of water-quality samples analyzed for ammonia nitrogen as N, pH, and water temperature.

Dissolved Oxygen

Dissolved oxygen is an essential element for aquatic life. Dissolved-oxygen requirements differ from species to species, life stages, and life processes. The State of Wisconsin water-quality standard for dissolved oxygen in warmwater streams is 5 mg/L. Smallmouth bass need a higher dissolved-oxygen concentration than many other fish for survival and growth (Bulkley, 1975). Healthy populations of warmwater fish need a minimum concentration of dissolved oxygen above 5 mg/L during the critical period and above 3 mg/L for the remaining part of the year (Chapman, 1986). Smallmouth bass typically die when the dissolved-oxygen concentration is near or below 1 mg/L for extended periods of time (Bulkley, 1975). These dissolved-oxygen concentration criteria are conservative, and smallmouth bass may tolerate concentrations less than these criteria.

Daily minimum dissolved-oxygen concentrations in the Little Platte River were never below the minimum dissolved-oxygen concentration for the adult life stage in 1987 and 1988 (fig. 6). On a number of days in 1988, minimum dissolved-oxygen concentrations were below the early-life-stage standard of 5 mg/L because of normal diurnal fluctuations. Overall, dissolved-oxygen concentrations declined in 1989. Daily minimums were below the early- and adult-life-stage minimum concentrations on numerous days in 1989 (fig. 6). In addition, a noteworthy reduction in dissolved-oxygen concentration occurred during a storm on August 5, 1989. A rainstorm of 1.16 in. increased the discharge from 10 ft^3/s to a peak discharge of 85 ft^3/s (fig. 7). As the discharge increased, the dissolved-oxygen concentration began to decrease. The maximum concentration on August 4 was 15.5 mg/L, whereas the minimum storm-induced dissolved-oxygen concentration on August 5 was 0.5 mg/L (fig. 7). The dissolved-oxygen concentration remained below 1 mg/L for about 5 hours.

Reductions in the dissolved-oxygen concentrations during runoff events may be caused by one or more factors; for example, (1) inflow of large volumes of runoff with low dissolved-oxygen concentration, (2) the influx or resuspension of oxygen-demanding materials as a result of storm-water input, (3) decreased oxygen solubility caused by increased water temperature, and (4) possible reduction of photosynthetic productivity (Graczyk and Sonzogni, 1991). A combination of these processes may be occurring in the Little Platte River.

Other dissolved-oxygen reductions in the Little Platte River were not induced by storm runoff. During a period from July 6 through July 10, 1989, the dissolved-oxygen minimum was below 3 mg/L for 5 days and below 2 mg/L for 1 day (fig. 7). A diurnal fluctuation of discharge and dissolved oxygen is shown in figure 7. A sewage-treatment plant at Platteville, Wis., discharges to a tributary upstream from the gaging station on the Little Platte River. The stream discharge fluctuates from about 10 ft^3/s to about 16 ft^3/s daily (fig. 7). Approximately 1.4 ft^3/s of the apparent 6 ft^3/s increase is discharge from the sewage-treatment plant, but the remainder of the flow increase is from unknown sources (R.A. Schlesser, Wisconsin Department of Natural Resources, unpublished data, 1991). A dairy and gravel pit upstream from the gaging station may discharge water to the Little Platte River during their normal operations.

The diurnal dissolved-oxygen fluctuation is caused by photosynthesis and respiration by aquatic plants. Concentrations of total phosphorus above 0.10 mg/L can accelerate plant growth in streams (U.S. Environmental Protection Agency, 1986). With increased algae and macrophytic biomass, the diurnal dissolved-oxygen fluctuations become increasingly pronounced. The sewage-treatment plant at Platteville does not have phosphorus-removal capabilities. Water samples collected at the Little Platte River gaging station during low flow had total-phosphorus concentrations greater than or equal to 0.30 mg/L for 1988-90 (table 5). The minimum total-phosphorus concentrations measured at the Little Platte River during low flows were higher than those measured at the other three sites (table 5). Minimum total-phosphorus concentrations for Rattlesnake Creek and Sinsinawa River were slightly greater than or less than 0.10 mg/L. Minimum total-phosphorus concentrations for Livingston Branch did not fall into either of these two patterns; the minimum concentration in 1988 was 0.22 mg/L, and in 1989 it was only 0.07 mg/L. The high minimum total-phosphorus concentrations at the Little Platte River may have been exacerbated

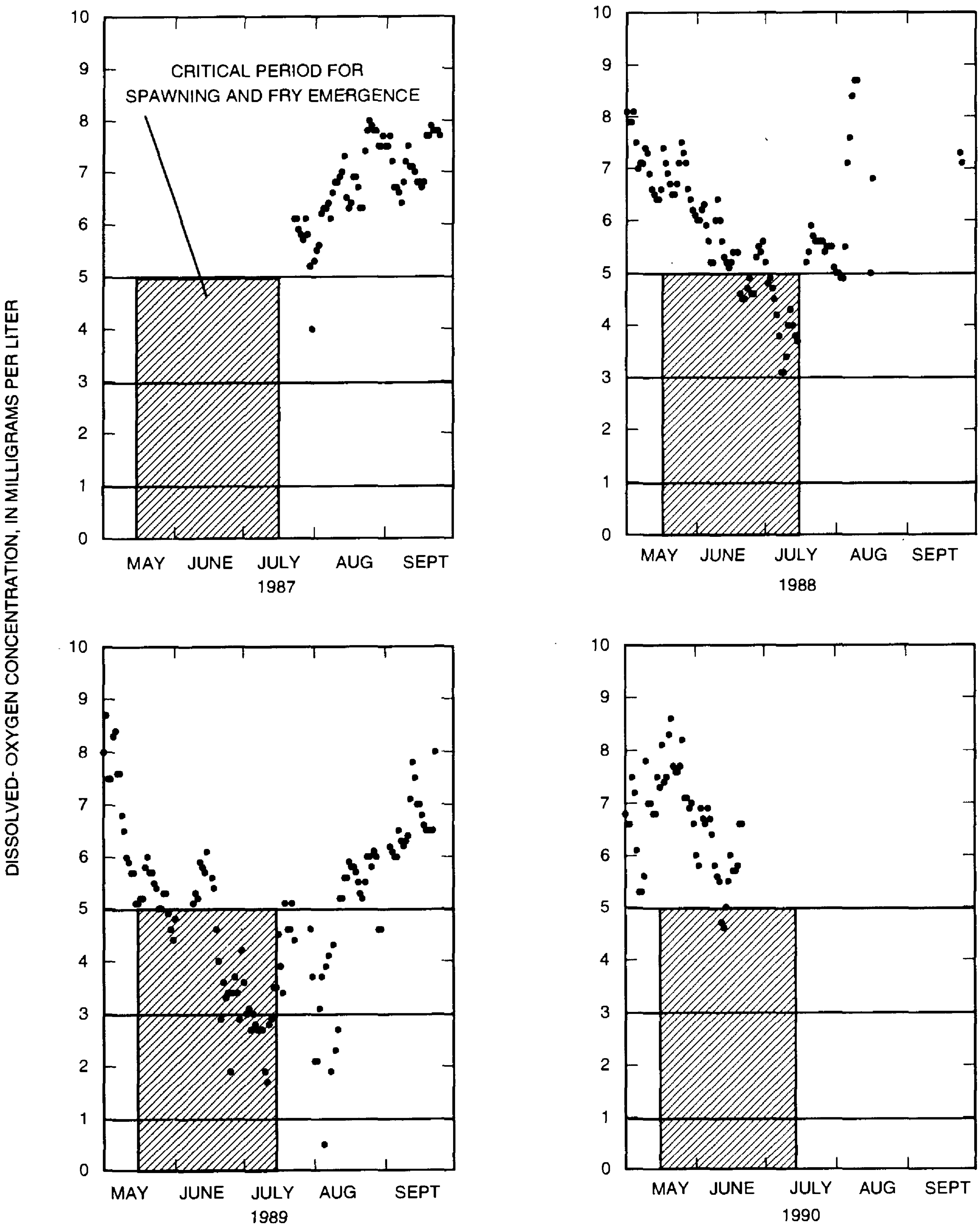

Figure 6. Minimum dissolved-oxygen concentration in the Little Platte River, May-September 1987-90. (5 milligrams per liter, minimum concentration for early life stage; 3 milligrams per liter, minimum concentration for adult life stage; 1 milligram per liter, concentration below which smallmouth bass are killed.)

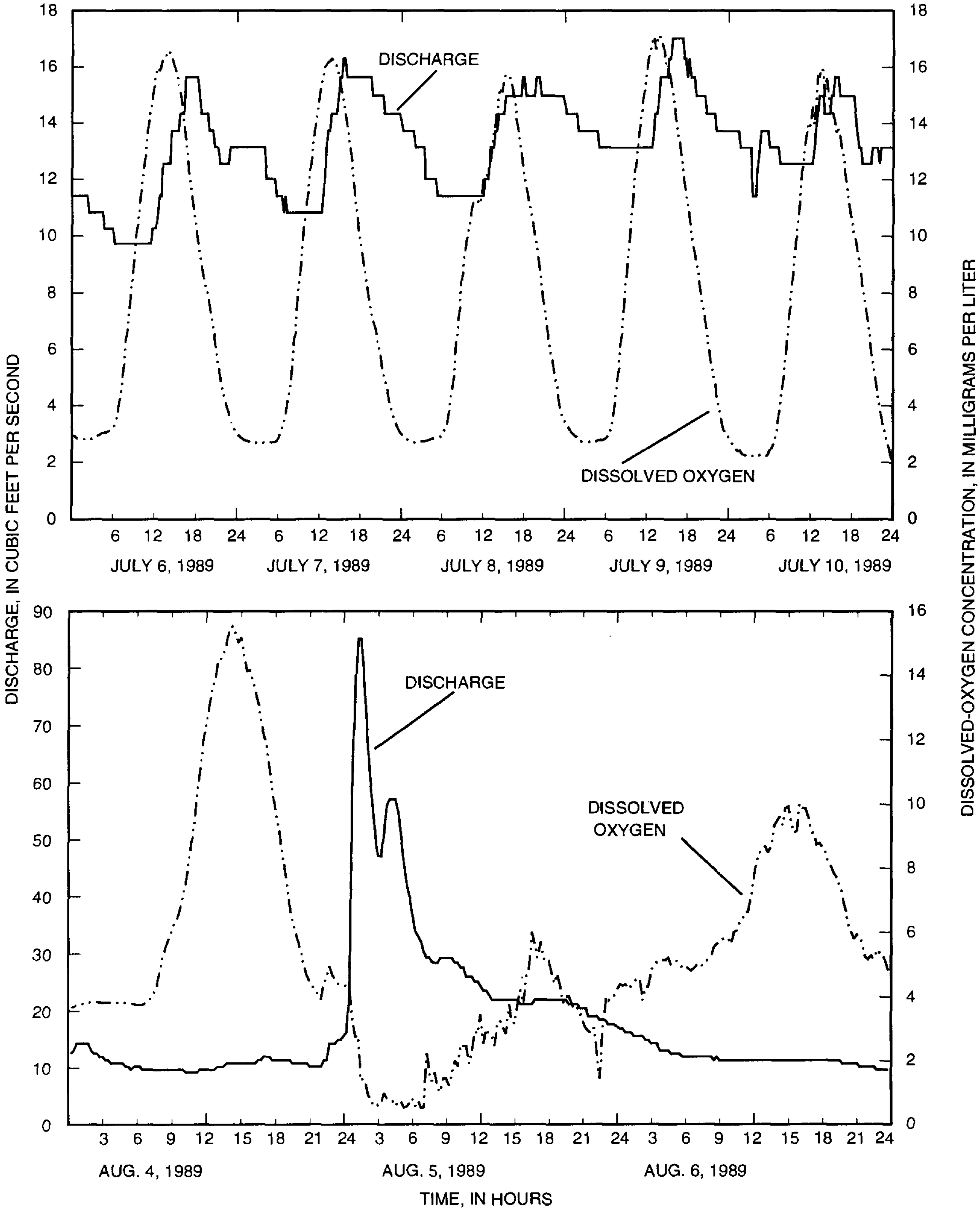

Figure 7. Discharge and dissolved-oxygen concentration in the Little Platte River, July 6-10 and August 4-6, 1989 (Wisconsin standard for dissolved oxygen is 5 milligrams per liter).

by the drought in southwestern Wisconsin in 1989. With a low base-flow runoff of 3.02 in. in 1989 as compared to 5.61 in. of base-flow runoff in 1988 (table 3), the total-phosphorus concentration may not have been diluted as much. Dissolved-oxygen concentrations were below the adult-life-stage minimum concentration for several days in a row. Smallmouth bass may leave reaches of low dissolved-oxygen concentration and move to areas where the concentration is higher (Bulkley, 1975).

Dissolved oxygen was monitored in the Little Platte River until late June 1990. Concentrations measuring less than the early-life-stage standard were recorded on only 2 days in 1990 (fig. 6).

In Livingston Branch, minimum dissolved-oxygen concentrations in 1987 were below the minimum concentration (1 mg/L) necessary to keep smallmouth bass alive and near that concentration in 1988 and 1990 (fig. 8). A peak discharge of 108 ft^3/s caused by 2.4 in. of rain resulted in a sharp decrease in the dissolved-oxygen concentration on July 31, 1987 (fig. 9). Minimum dissolved-oxygen concentrations as low as 0.5 mg/L were recorded, and dissolved-oxygen concentrations were less than 5 mg/L for about 7 hours. The probable cause or causes of these low dissolved-oxygen concentrations are the same as for the Little Platte River. Minimum daily dissolved-oxygen concentrations below the recommended minimum concentration of dissolved oxygen for the adult life stage of smallmouth bass were recorded on four other days in 1987.

On 5 days in 1988, dissolved-oxygen concentrations were below the adult-life-stage minimum concentration (fig. 8). The dissolved-oxygen concentration on one of these days in September was near 1 mg/L. On numerous days in 1988, concentrations were below the early-life-stage standard (5 mg/L) during the critical spawning period and fry-emergence period because of normal diurnal fluctuations (fig. 8).

No daily minimum was below the adult-life-stage minimum concentration (3 mg/L) in 1989, but numerous daily minimums during the critical period were below the early-life-stage standard (5 mg/L) because of normal diurnal fluctuations (fig. 8).

In August 1990, there were 2 days when minimum dissolved-oxygen concentrations were below the standard for the adult life stage. Minimum daily concentrations were below the early-life-stage standard for fewer days during the critical period in 1990 (fig. 8) as compared to 1988 and 1989.

In 1987, minimum dissolved-oxygen concentrations in Rattlesnake Creek were occasionally below the minimum concentration necessary to keep smallmouth bass alive (fig. 10). These especially low dissolved-oxygen concentrations occurred during or after storms in the basin. In both July and September, the dissolved-oxygen concentration was reduced to less than 0.1 mg/L for a brief period. A rainstorm of 2.8 in. on July 29, 1987, increased the discharge to a peak of 1,130 ft^3/s (fig. 11). The dissolved-oxygen concentration was reduced to less than 0.1 mg/L for 1-1/2 hours and was less than 1 mg/L for 5-1/2 hours during the storm (fig. 11). On September 17, 1987, when the discharge increased from 19 ft^3/s to 95 ft^3/s (fig. 11), the dissolved-oxygen concentration decreased to virtually zero during the storm. The maximum dissolved-oxygen concentration on the previous day had been 11.6 mg/L (fig. 11). The dissolved-oxygen concentration was less than 0.1 mg/L for 2-1/2 hours during the storm and stayed below the Wisconsin standard of 5 mg/L well into the next day (fig. 11).

The minimum dissolved-oxygen concentrations were below the reported minimum concentration necessary for the adult life stage (3 mg/L) in Rattlesnake Creek also during 4 days in 1987 (fig. 10). In 1988, no measured daily minimum dissolved-oxygen concentrations were below the minimum dissolved-oxygen concentration of the adult life stage (3 mg/L) or the concentration necessary for survival of smallmouth bass (1 mg/L) (fig. 10). On numerous days in 1988, minimum dissolved-oxygen concentrations were below the early-life-stage concentration standard (5 mg/L) during the critical period because of diurnal fluctuations. On a number of days in the critical period in 1989, dissolved-oxygen minimum concentrations were below 5 mg/L (fig. 10). In 1989, there were also 4 days when dissolved-oxygen minimum concentrations were below the necessary concentration for the adult life stage, but none below 1 mg/L (fig. 10). Fewer days in 1990 were char-

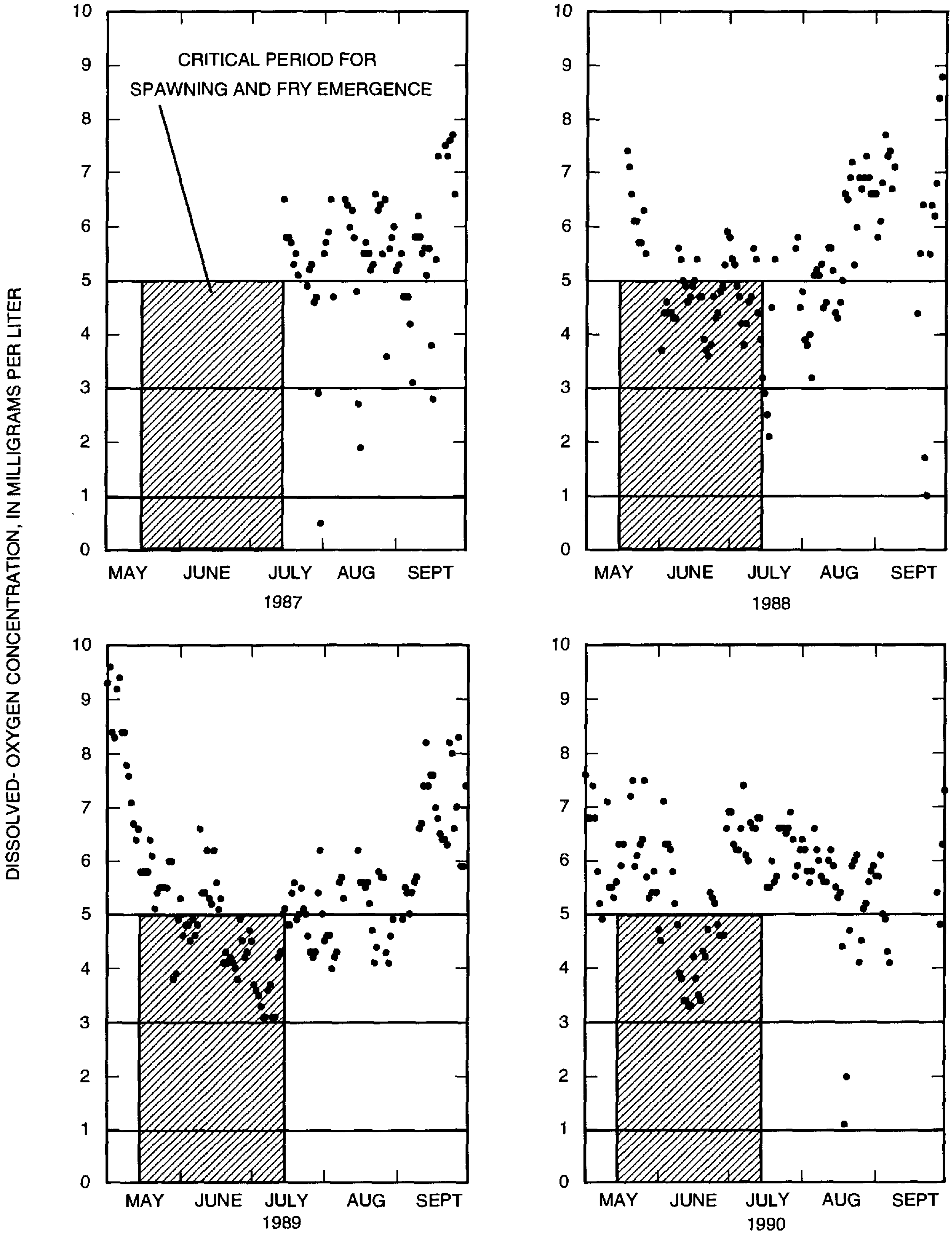

Figure 8. Minimum daily dissolved-oxygen concentration in Livingston Branch of the Pecatonica River, May-September 1987-90. (5 milligrams per liter, minimum concentration for early life stage; 3 milligrams per liter, minimum concentration for adult life stage; 1 milligram per liter, concentration below which smallmouth bass are killed.)

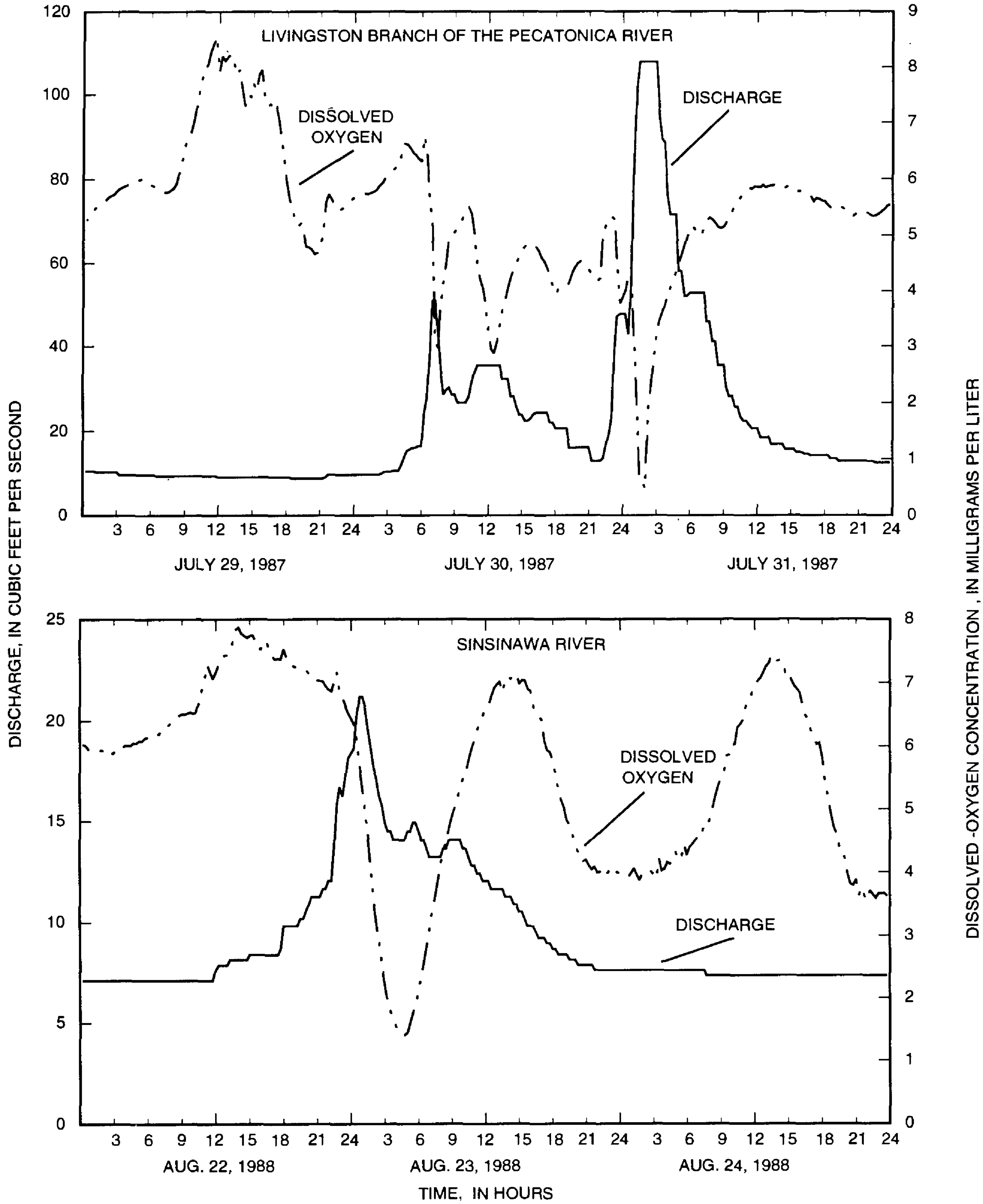

Figure 9. Discharge and dissolved-oxygen concentration in Livingston Branch of the Pecatonica River, July 29-31, 1987, and the Sinsinawa River, August 22-24, 1988. (Wisconsin standard for dissolved oxygen is 5 milligrams per liter).

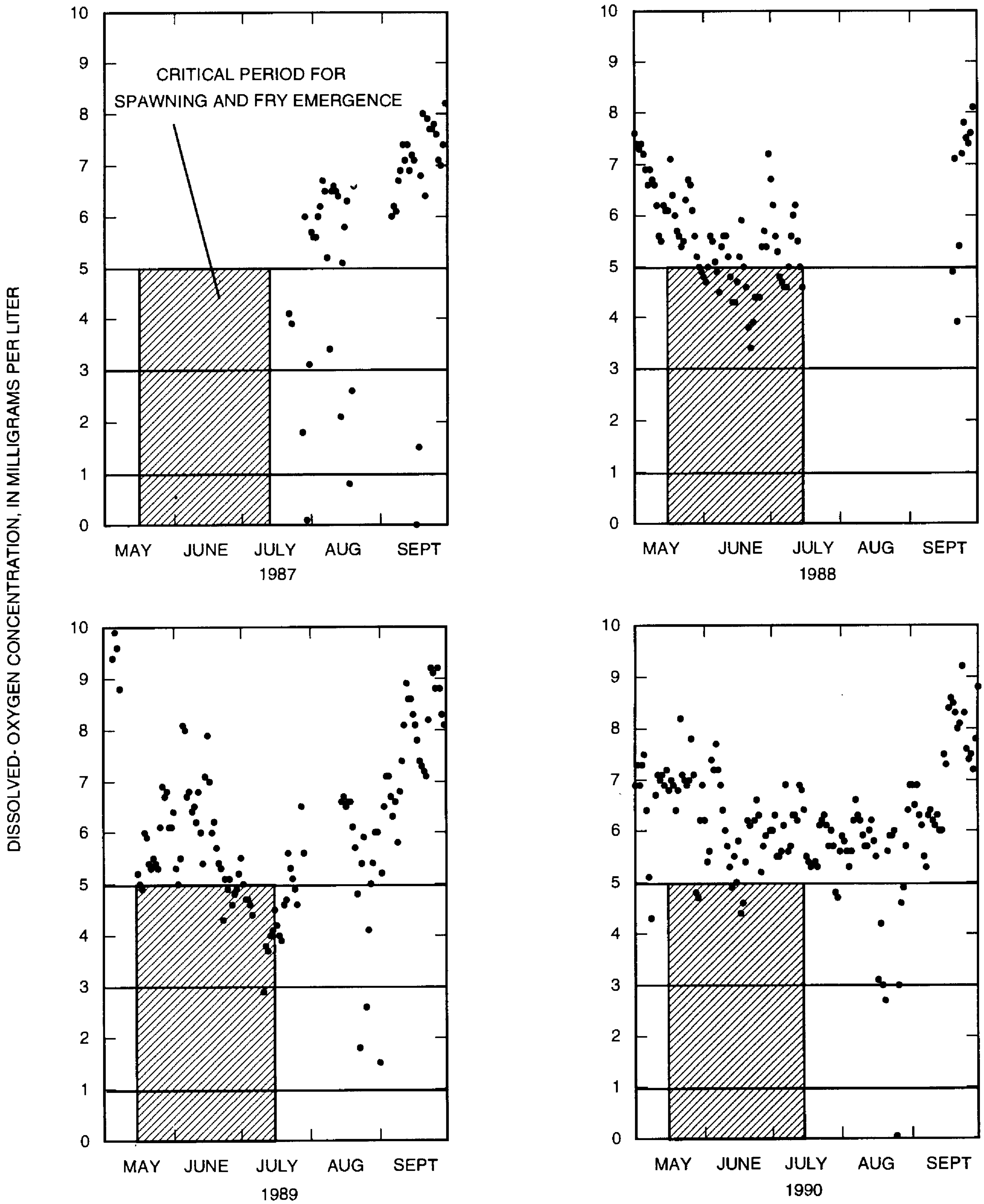

Figure 10. Minimum daily dissolved-oxygen concentration in Rattlesnake Creek, May-September 1987-90. (5 milligrams per liter, minimum concentration for early life stage; 3 milligrams per liter, minimum concentration for adult stage; 1 milligram per liter, concentration below which smallmouth bass are killed.)

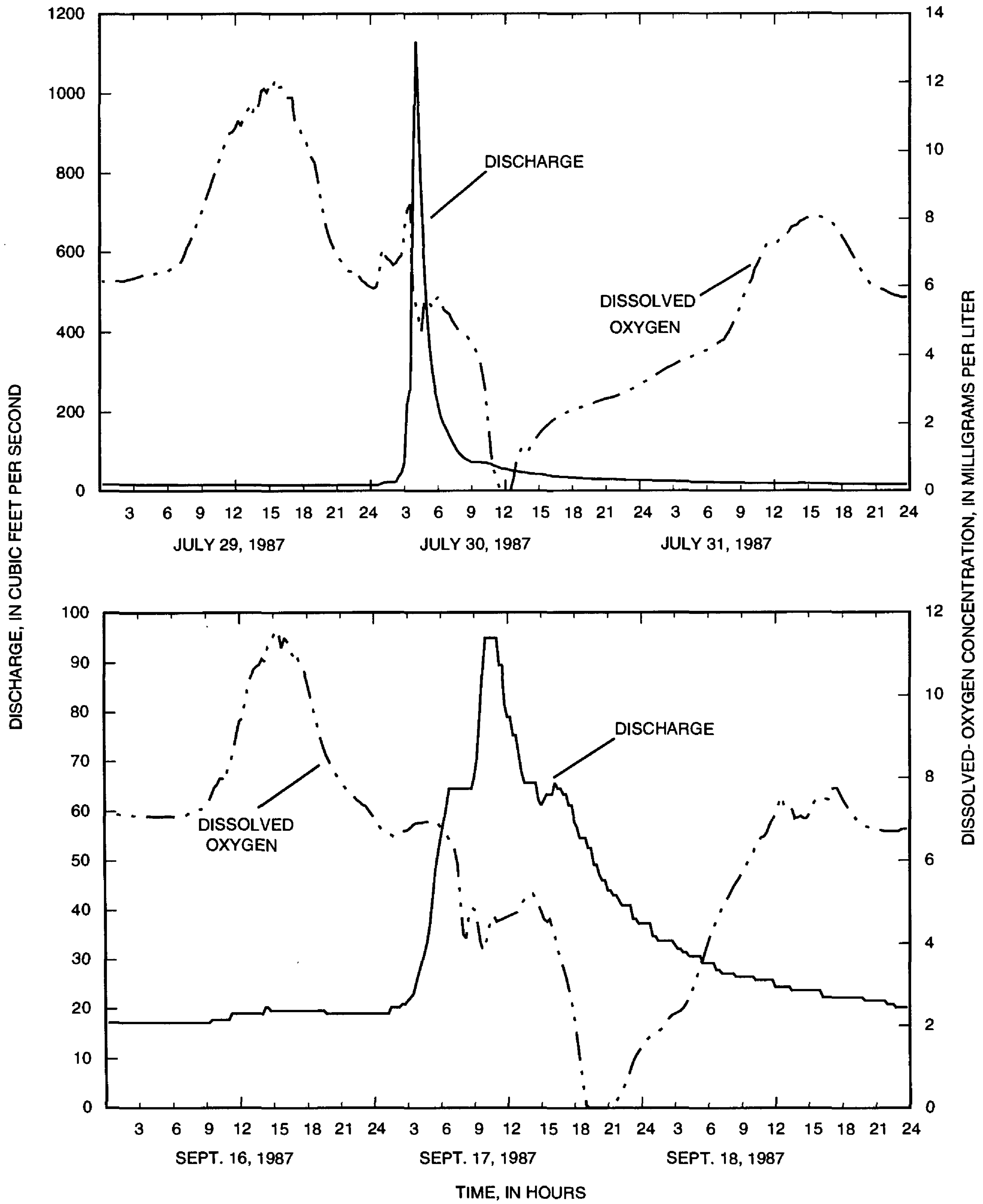

Figure 11. Discharge and dissolved-oxygen concentration in Rattlesnake Creek, July 29-31 and September 16-18, 1987 (Wisconsin standard for dissolved oxygen is 5 milligrams per liter).

acterized by minimum dissolved-oxygen concentrations below the early-life-stage standard during the critical period. In August, there were 4 days when dissolved-oxygen concentration was at or near the adult-life-stage minimum and 1 day when the dissolved-oxygen concentration was reduced to less than 0.5 mg/L (fig. 10), well below the 1 mg/L concentration necessary to sustain life.

In 1987 at the Sinsinawa River, there were no days when minimum daily dissolved-oxygen concentrations were below the 3-mg/L adult-life-stage minimum dissolved-oxygen concentration (fig. 12). On numerous days during the critical period in 1988, minimum dissolved-oxygen concentrations were below the standard for early life stages of smallmouth bass because of normal diurnal fluctuation (fig. 12). On 3 days, daily minimums were below the adult-life-stage minimum concentration but were never below 1 mg/L. A rainstorm of 1.12 in. increased the discharge from 7.1 ft^3/s on August 22, 1988, to a peak discharge of 21 ft^3/s on August 23, 1988 (fig. 9). During the rising limb of the hydrograph, the dissolved-oxygen concentration started to decline and was at a minimum of 1.4 mg/L 4 hours after the peak discharge. This dissolved-oxygen reduction is consistent with that of the Little Platte River, Rattlesnake Creek, and Livingston Branch, in that minimum dissolved-oxygen concentrations occurred at or near the peak discharge. The probable cause or causes of this reduction in dissolved-oxygen concentration are the same as for the other basins studied. In 1989, minimum dissolved-oxygen concentrations improved. Daily minimum dissolved-oxygen concentrations were still below the early-life-stage minimum concentration during the critical period, but none were below the 3.0 mg/L minimum concentration for the adult life stage (fig. 12). On 2 days during the critical period in 1990, minimum dissolved-oxygen concentrations were below the adult-life-stage minimum. On a number of days, the dissolved-oxygen concentrations were below the early-life-stage minimum concentration. Data collection for dissolved oxygen ended in June at the Sinsinawa River, thus no additional data from July through September 1990 were available.

Water Temperature

The optimum temperature range for smallmouth bass is reported to be 21 to 31°C; water temperatures above 36°C and at or near freezing have been found to be lethal to smallmouth bass (Barans and Tubb, 1973; Cherry and others, 1975; Reynolds and Casterlin, 1976). Optimum water temperature for initiation of nest building and spawning is variable and ranges from 15 to 21°C (Becker, 1983). Maximum and minimum water temperatures for the study sites (1987 through 1990) are listed in table 7.

Winter minimum water temperatures of 0°C were recorded at all of the sites during winter months in 1988, 1989, and 1990. Winter water temperatures for 1987 were not recorded because the temperature probe was not installed until summer 1987 (table 7). Typically, all of the streams became completely covered with ice in the winter.

Even though winter water temperatures at all of the sites were 0°C, these water temperatures probably were not lethal to smallmouth bass. Smallmouth bass may migrate out of their summer waters to larger river systems with deep pools (Langhurst and Shoenike, 1990). These deep pools may have water temperatures more suitable for smallmouth bass in the winter.

During this study period, none of the rivers had maximum water temperatures greater than the reported lethal temperature of 36°C (table 7).

A frequency analysis of the percentage of time that daily mean water temperature was in the optimum water temperature range of 21 to 31°C for 1987-90 is found in table 8. In 1987 at all of the sites, data were collected for only part of the year (July through September) and in 1990, at the Little Platte and Sinsinawa Rivers, data were collected from October through June. The percentage of time, in days, that the water temperature was in the optimum water temperature range was not calculated. In 1988 and 1989, on about 20 percent of days that year, the daily mean water temperature was in the optimum temperature range for some unspecified time period. Temperature of the Little Platte River was in the optimum temperature range on

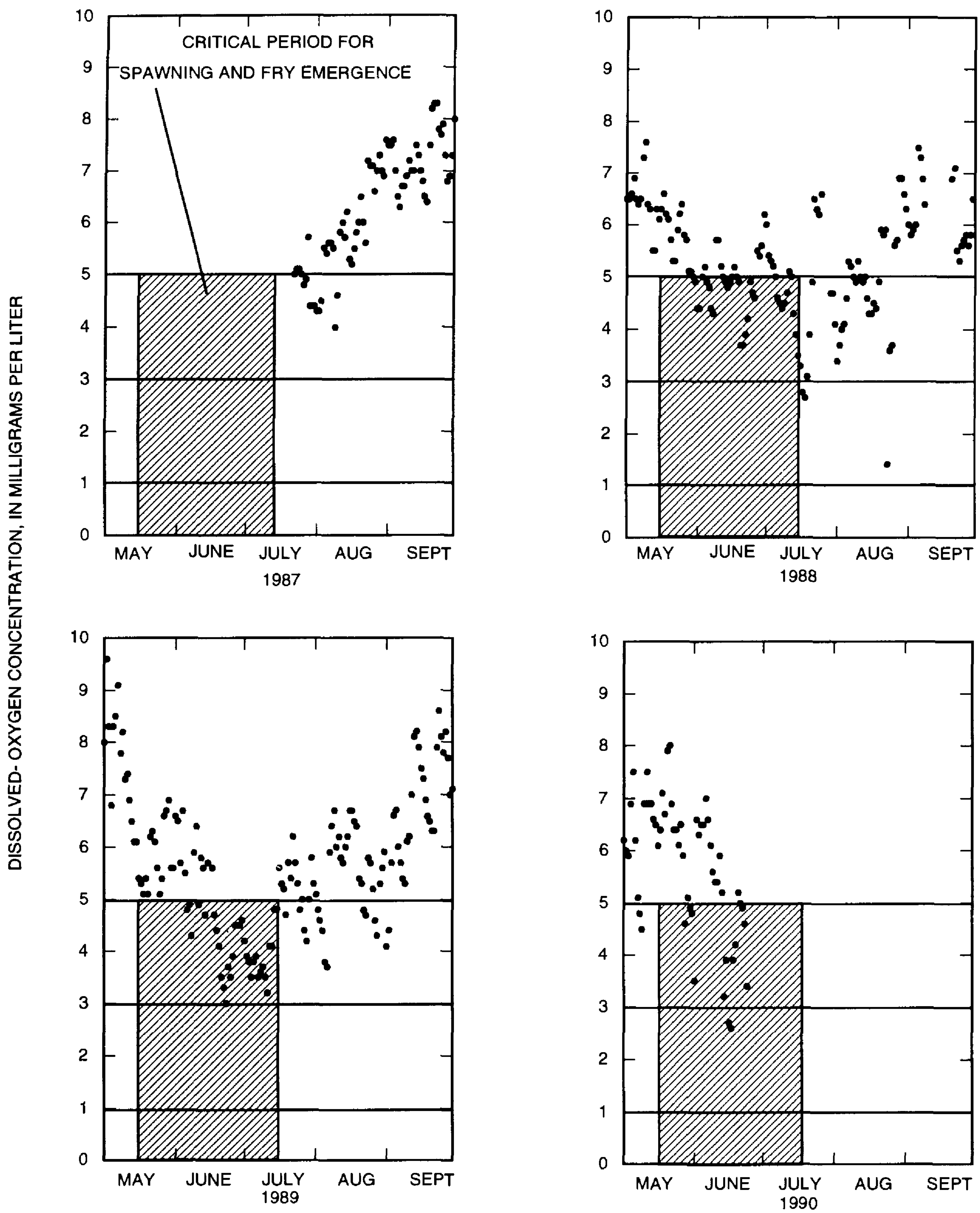

Figure 12. Minimum daily dissolved-oxygen concentration in the Sinsinawa River, May-September 1987-90. (5 milligrams per liter, minimum concentration for early life stage; 3 milligrams per liter, minimum concentration for adult life stage; 1 milligram per liter, concentration below which smallmouth bass are killed.)

Table 7. *Maximum and minimum water temperatures in the four study streams, 1987-90*

[Data shown in degrees Celsius; Max, maximum; Min, minimum]

Stream	Water year							
	[1]1987		1988		1989		1990	
	Max	Min	Max	Min	Max	Min	Max	Min
Little Platte River	26	14	32	0	32	0	[2]27	[2]0
Livingston Branch of the Pecatonica River	32.5	11	32	0	35	0	31.5	0
Rattlesnake Creek	30.5	12.5	31.5	0	35	0	30	0
Sinsinawa River	30	12.5	31	0	32	0	[2]28.5	[2]0

[1] Data collected July through September 30.
[2] Data collected October through June.

Table 8. *Percentage of days that year that daily mean water temperature was in the optimum water temperature range of 21 to 31 degrees Celsius, 1987-90*

[--, no data available]

Stream	Water year			
	1987	1988	1989	1990
Little Platte River	--	28	25	--
Livingston Branch of the Pecatonica River	--	19	20	21
Rattlesnake Creek	--	20	20	20
Sinsinawa River	--	25	23	--

more days in 1988 and 1989 than in the other three streams.

Pesticides

Samples of the water-sediment mixture and the bottom material were analyzed for pesticides commonly used in the basins. The pesticides analyzed were a combination of insecticides and herbicides. Although the chlorinated hydrocarbon insecticides have been found to be the most toxic to smallmouth bass (Bulkley, 1975), they were not analyzed for because they are not used in the basin (Wisconsin Department of Agriculture, Trade, and Consumer Protection, 1985). Generally, herbicides are less toxic to smallmouth bass than most insecticides. Summary statistics of the pesticides sampled for during 1987-90 are listed in table 9.

Pesticides in Water-Sediment Mixture

All samples contained insecticide concentrations below the detection limit except for one sample collected at the Little Platte River. This sample had a carbofuran concentration of 0.44 µg/L. The LC_{50}96 hr (lethal concentration for 50 percent of test organisms after 96 hours exposure) for bluegills (same family as smallmouth bass) for carbofuran is 250 µg/L (Johnson and Finley, 1980). The maximum Little Platte River concentration was well below the lethal concentration for carbofuran.

Table 9. *Summary of pesticide data in water-sediment mixture samples for the study streams, 1987-90*

[Units in micrograms per liter unless specified otherwise; <, less than analytical reporting limit; Max, maximum; Min, minimum; --, no statistics calculated; ND, not detected]

	Little Platte River			Livingston Branch of Pecatonica River			Rattlesnake Creek			Sinsinawa River		
Pesticide	Number of samples	Max	Min	Number of samples	Max	Min	Number of samples	Max	Min	Number of samples	Max	Min
						Insecticides						
Chlorpyrifos	11	<1	--	7	<1	--	4	<1	--	6	<8	--
Phorate	11	ND	--	7	ND	--	4	ND	--	6	<.60	--
Terbufos	11	<.60	--	7	ND	--	4	<.50	--	6	<.50	--
Fonofos	11	ND	--	7	ND	--	4	<.20	--	6	ND	--
Carbofuran	11	.44	ND	7	<16	--	4	<20	--	6	<33	ND
						Herbicides						
Metolachlor	11	12	ND	7	2	ND	4	ND	--	6	110	ND
Atrazine	11	15	.11	7	1.4	<.28	4	34	ND	6	97	.11
Alachlor	11	3	ND	7	2.2	ND	4	5.9	ND	6	29	ND
Cyanazine	11	8.3	ND	7	1.6	ND	4	28	ND	6	84	ND

Detectable concentrations of herbicides were found in water-sediment mixture samples from all of the stations (table 9). Herbicide concentrations were highest at the Sinsinawa River; the highest concentration was for metolachlor, at 110 µg/L, and concentrations of atrazine and cyanazine were the next highest at 97 µg/L and 84 µg/L, respectively.

Herbicides were detected at the other three sites, except for metolachlor at Rattlesnake Creek. The concentrations of the herbicides at the other three sites were all lower than the concentrations at the Sinsinawa River (table 9).

Herbicides are more likely to affect primary producers (algae and macrophytes) than smallmouth bass. Smallmouth bass and macroinvertebrates can be affected by herbicides through disturbance of the food chain. Smallmouth bass in the fry and juvenile life stages would be the most severely affected. Moreover, macroinvertebrates that feed on the primary producers would be more directly affected by disturbance of the food chain than would smallmouth bass.

Pesticides in Bottom Materials

Pesticides that are carried in the water column can be deposited in the streambed. Bed-material samples were collected and analyzed for the same pesticides that were analyzed for in the water-sediment mixture. Endosulfan, an insecticide, was also analyzed for in the bed-material samples. Endosulfan, which is highly toxic, can accumulate in bed materials. No pesticides were found above an analytical reporting limit in the bed-material samples.

Summary

A severe drought affected surface-water characteristics in southwestern Wisconsin and the upper Midwest in 1988 and 1989. Precipitation in all four study basins was below normal in 1988 and 1989. Precipitation ranged from 9.91 to 12.42 in. below the 1951-80 normal precipitation of 32.88 in. Combined May and June precipitation greater than 7 in. can adversely affect smallmouth bass reproductive success. Total precipitation for May and June was less than 7 in. in 1988 and 1989, but greater than 7 in. in 1987 and 1990 in all four basins.

Annual mean discharge was lowest in 1989 at all four basins except for Rattlesnake Creek. Rattlesnake Creek had the lowest mean annual discharge in 1990. Years with low overland-flow runoff during the critical reproductive period for smallmouth bass (mid-May to mid-July) will usually result in good reproductive success. Overland-flow runoff at all four sites was very low in 1988--less than 5 percent of the total runoff during the critical period. The trend of low overland-flow runoff continued in 1989 at the four sites. Overland-flow runoff increased at Rattlesnake Creek and Livingston Branch of the Pecatonica River in 1990; during the critical period, overland-flow runoff at Livingston Branch of the Pecatonica River was 1.38 in. (70 percent of total runoff).

Another determinant of smallmouth bass abundance is a stable stream stage during the critical reproductive period. Stream stages were stable in 1988 and 1989 at all four basins. No stream stages rose 0.5 ft or greater. These stable stream stages were conducive to good reproductive success of smallmouth bass. In contrast, all four streams rose by greater than 0.5 ft during the critical period in 1990. Stream stages rose by more than 10 ft in one day at Livingston Branch of the Pecatonica River and by more than 7 ft at the Little Platte River.

The un-ionized fraction of ammonia nitrogen as N was occasionally above the Wisconsin standard of 0.04 mg/L at all four sites. The maximum concentration measured, 0.10 mg/L at Rattlesnake Creek, was below the concentration toxic to smallmouth bass.

Short-term high concentrations of suspended solids exceeded published standards for maintaining warmwater fisheries. These elevated concentrations lasted for short periods of time only and were not thought to be particularly harmful to smallmouth bass populations.

Dissolved-oxygen concentrations were reduced to or below the reported concentration necessary for smallmouth bass survival of 1 mg/L during storms in 1987 at Rattlesnake Creek and Livingston Branch of the Pecatonica River. In 1988, dissolved-oxygen concentrations were reduced to near 1 mg/L during storms at Livingston Branch of the Pecatonica River and the Sinsinawa River. In 1989, dissolved-oxygen concentrations in the Little Platte River and Rattlesnake Creek were at or near 1 mg/L during storms. In 1990, only Rattlesnake Creek and Livingston Branch of the Pecatonica River had dissolved-oxygen concentrations near or below 1 mg/L. These dissolved-oxygen concentration reductions to below 1.0 mg/L or near zero all occurred during or just after increasing streamflows that resulted from precipitation. Dissolved-oxygen concentrations in all of the streams were frequently below 5 mg/L, the reported minimum tolerable dissolved-oxygen concentration of the early life stages of smallmouth bass during the critical reproductive period. Dissolved-oxygen concentrations also were below 3 mg/L (the reported minimum tolerable dissolved-oxygen concentration of the adult life stage) for numerous days during the study.

Samples of water-sediment mixture and bed material were analyzed for herbicides and insecticides. Herbicides, primarily the triazines, were found at all of the sites but at concentrations that were probably not directly harmful to smallmouth bass. One sample from the Little Platte River had a detectable carbofuran concentration, but it was well below the concentration lethal to fish. No pesticides were detected in any of the bed-material samples at any of the sites.

MACROINVERTEBRATE POPULATIONS

by Richard A. Lillie[3] and Roger A. Schlesser[4]

Populations in Study Streams

Macroinvertebrates are excellent indicators of water quality and have several advantages over fish as biomonitors of water quality because of their relatively sedentary nature. Because macroinvertebrates spend most of their life cycle within small areas of a river, even short-term, minor environmental perturbations can have long-lasting effects on macroinvertebrate communities (Berkman and others, 1986). In this study, macroinvertebrate data were evaluated in context with changes in, and differences among, hydrology and water quality in the four study streams.

A number of qualitative and quantitative attributes of macroinvertebrate communities were used to measure changes in water quality. These attributes, or metrics, differ in their sensitivities to various forms of contamination. Taxa richness generally responds directly to changes in water quality (that is, the greater the numbers of macroinvertebrate taxa, the better the water quality). The number of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT) taxa richness also corresponds directly to changing water quality and is considered more sensitive to contamination than total taxa richness (Plafkin and others, 1989).

The abundances of total macroinvertebrates or various selected taxa provide some indication of standing crop and trophic status. Very high abundances of pollution-tolerant taxa can indicate nutrient enrichment and high trophic status. Conversely, low abundances of macroinvertebrates can be associated with either good (low concentrations of nutrients) or poor (high concentrations of nutrients) water quality. In the former case, low nutrient availability limits production, whereas in the latter case, either hydraulic washout, substrate abrasion, or toxics may limit or reduce production.

Differences in taxa composition (percentage of total) among rivers should also correspond with basic differences in either water quality or physicochemical data. The abundance and relative composition of functional-feeding classes of macroinvertebrates within rivers can be informative. For example, the relative contribution of organisms whose primary mode of food gathering is by scraping (scrapers) provides some indication of the availability of periphyton (primarily diatoms) in the river. If organic enrichment is excessive, the periphyton community can take the form of filamentous algae; scrapers cannot feed efficiently, and they may decline in abundance. In contrast, filamentous algae make ideal attachment sites for organisms that obtain their food by filtering (filter feeders). The ratio between scrapers and filter feeders has also been proposed as an index to water quality. Large populations of midges (chironomids), relative to other taxa, may indicate different forms of environmental stress, including possible heavy-metal contamination. The ratio of EPT taxa to midges also has been proposed as an indicator of the health of the community.

An even balance among mayflies, stoneflies, caddisflies, and midges indicates a stable biotic condition. The presence of large numbers or a disproportionate number of shredders indicates greater availability of coarse particulate organic matter (CPOM), defined as greater than 1 mm. The relative contribution of those organisms that feed primarily on fine particulate organic matter (FPOM), defined as less than 1 mm, has been used as an environmental indicator in Texas (Twidwell and Davis, 1989). High percentages of FPOM-feeding organisms indicate limited aquatic use or poor water quality. Filter feeders (primarily caddisflies) and collector/gatherers (mostly midges) both utilize fine particulate matter as their primary food source. The degree of similarity among macroinvertebrate communities (based on functional-feeding classes) can be useful in evaluating the direction of trends in water quality (Pontasch and Brusven, 1988; Pedersen and Perkins, 1986).

[3]Wisconsin Department of Natural Resources, 1350 Femrite Drive, Monona, WI 53716.
[4]Wisconsin Department of Natural Resources, Southern Headquarters, 3911 Fish Hatchery Road, Fitchburg, WI 53711.

Biotic-index (BI) data reflect the average pollution tolerance of a random subsample of organisms inhabiting riffles (Hilsenhoff, 1987). Increases in BI values indicate deterioration in water quality, whereas decreases in BI values indicate improvements in water quality.

Little Platte River

Fifty-five macroinvertebrate taxa were collected from the Little Platte River and its tributaries during the study. A complete taxa listing for each of the four streams is available from the authors upon request. Total taxa richness within the main study reach ranged from 11 to 30 taxa (fig. 13). Mean total taxa richness increased substantially during the fall 1989 sampling period but then declined during the spring 1990 (fig. 13). EPT taxa richness ranged from 3 to 12 taxa, and mean EPT taxa richness increased in fall 1989 and then declined the following spring (fig. 13).

Mean total macroinvertebrate abundance ranged from 4,550 to 15,100 individuals/m^2 and averaged 10,200 individuals/m^2 for the four sampling dates. Total macroinvertebrate abundance declined by almost 70 percent from October 1987 to October 1988 (fig. 14). All taxa decreased during this period, but only decreases in abundance of riffle beetles and total insects were statistically significant at the 5-percent probability level (ANOVA-Tukey method)

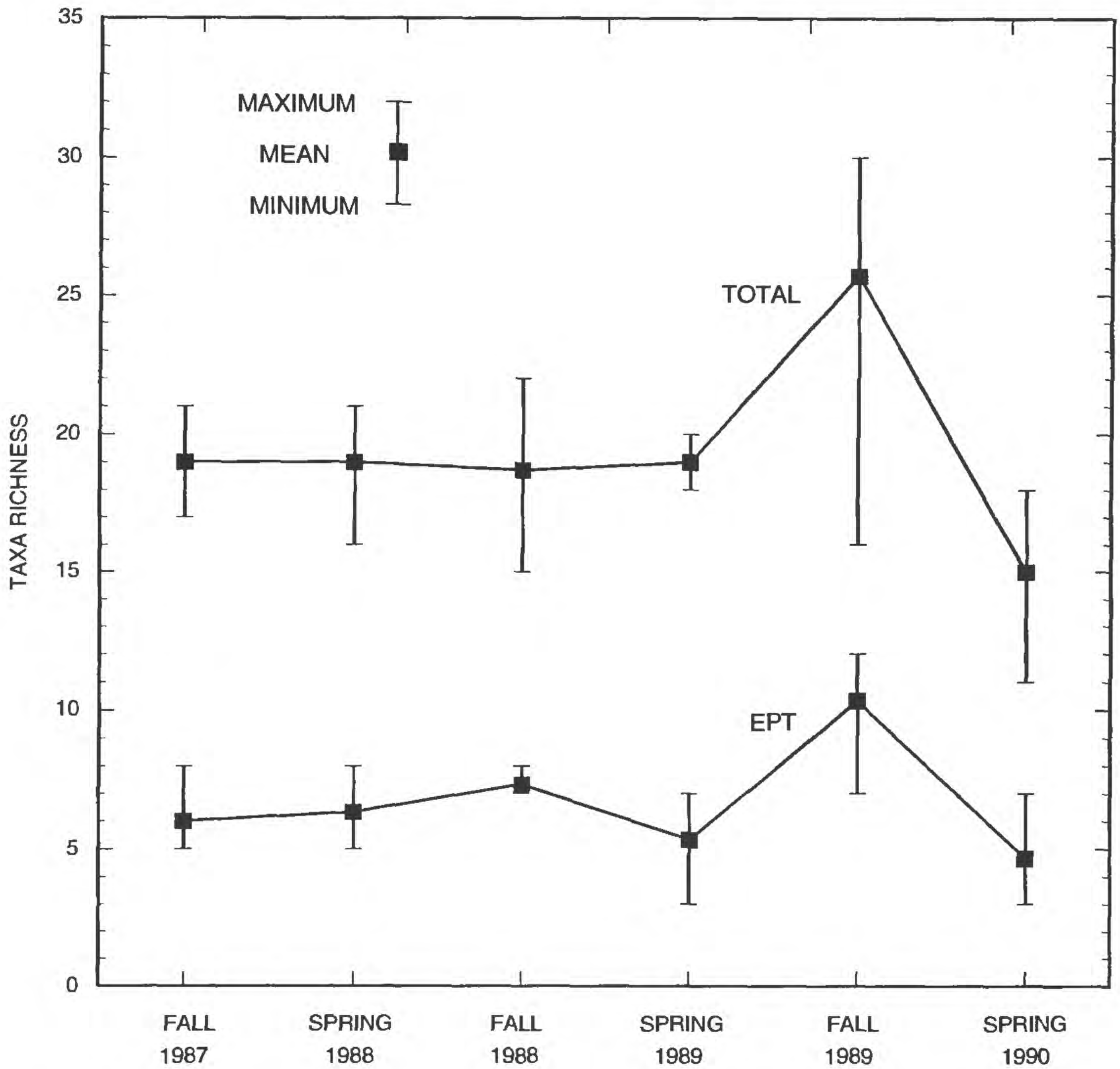

Figure 13. Total taxa richness and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness in the Little Platte River, fall and spring 1987-90.

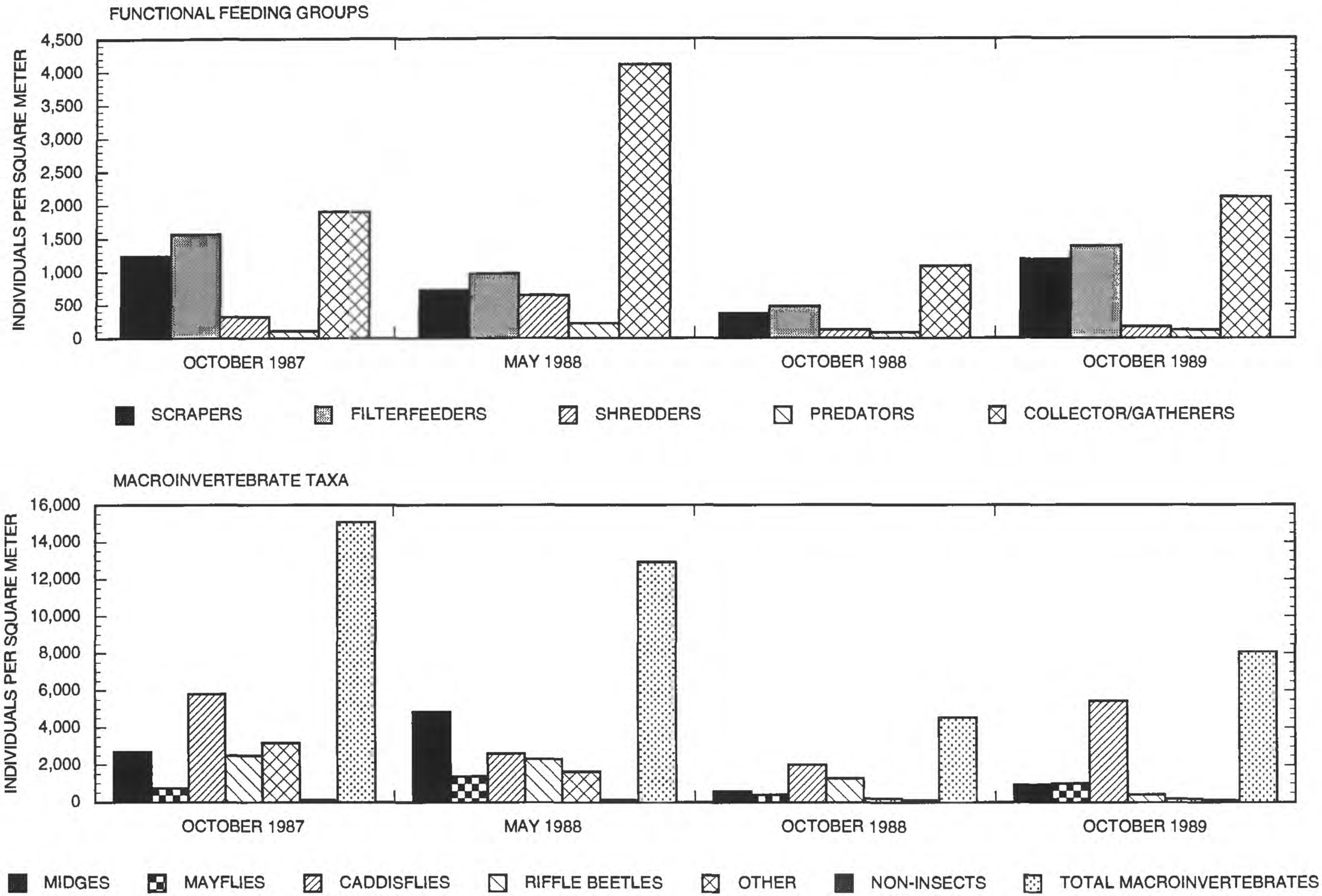

Figure 14. Abundances of macroinvertebrates and functional-feeding classes in the Little Platte River, October 1987, May 1988, and October 1988 and 1989.

(SAS, 1985). All taxa, except riffle beetles, increased in abundance from October 1988 to October 1989. Scrapers and collector/gatherers declined significantly during the period October 1987 to October 1988 (probability is less than 5 percent); filter feeders declined during 1988 (however, probability is greater than 5 percent), but returned to near the initial levels of abundance in 1989 (fig. 14). The abundances of several taxa and functional classes were significantly higher in the main study reach than in tributaries (probability is less than 5 percent). Mayflies were more abundant at upstream stations in the main study reach during the October 1987 sampling period (probability is less than 5 percent).

A mixture of caddisflies, midges, and riffle beetles dominated the macroinvertebrate fauna of the Little Platte River, and mayflies were of secondary importance. The relative contribution of riffle beetles (scrapers) was significantly reduced during October 1989 (probability was less than 5 percent). Among functional-feeding classes, collector/gatherers and filter feeders predominated, but scrapers occasionally were relatively abundant (fig. 14). Riffle beetles, midges, and predators were significantly more abundant at stations in the main study reach than in tributaries in October 1987 (probability is less than 5 percent). Mayflies were more abundant at upstream stations relative to downstream stations within the main study reach in October 1987 (probability was less than 5 percent). The contribution of FPOM processors, which was generally quite high in the Little Platte River, declined substantially during the fall 1988 sampling period (table 10). The percentage of FPOM organisms increased, however, during the subsequent sampling period.

Bray-Curtis dissimilarity coefficients provide some indication of relative change in community composition (functional-feeding classes) of main study segments among dates (Bray and Curtis, 1957) (table 11). The community composition of the Little Platte River changed very little over the first winter of the study, as indicated by low dissimilarity values (table 11). Community composition changed substantially between spring of 1988 and fall of 1988, however, accounting for an even larger degree of dissimilarity between the fall 1987 and fall 1988 communities. The high dissimilarity between the fall 1988 and fall 1989 communities seems to represent a reversion to 1987 conditions, as evidenced by the low dissimilarity between fall 1987 and fall 1989 communities.

Biotic-index (BI) values in the Little Platte River ranged mostly from good to fair (fig. 15). Overall water quality, based on both sets of BI values, was rated as good (table 12). There was some indication that water quality deteriorated within the Little Platte River during the study (fall 1988 to spring 1989, fig. 15). BI values from samples taken by personnel of the Dodgeville area WDNR office (six sampling dates with three replicates per sampling date) were slightly higher during the last three sampling periods, and BI values from samples taken by personnel of the Water Resource Research section of the WDNR (three sampling dates with six replicates per sampling date) increased (indicating deteriorating water quality from fall 1987 to fall 1989; table 12). BI values in tributaries were higher than in the main study reach on all three dates (table 13). On one occasion, the Rountree Branch tributary had a lower BI (improving water quality) than main study stations (fig. 15).

Livingston Branch of the Pecatonica River

Forty-four macroinvertebrate taxa were collected from Livingston Branch and its tributaries. Total taxa richness within the main study reach ranged from 11 to 22 taxa, and mean total taxa richness increased slightly during the fall 1989 sampling period (fig. 16). EPT taxa richness ranged from 1 to 8 (fig. 16). Spring samples generally contained fewer EPT taxa than fall samples. Total taxa counts were lowest during the fall 1987, whereas EPT taxa counts were lowest during the spring 1989 sampling period.

Mean total macroinvertebrate abundance ranged from 3,130 to 12,200 individuals/m^2 and averaged 7,420 individuals/m^2 for the four sampling dates. Total macroinvertebrate abundance declined from October 1987 to May 1988 (decreased 75 percent) and then partially recovered (increased 125 percent) by October 1988. This abundance level was maintained through October 1989 (fig. 17). Most changes in total numbers were attributable to fluctuations in the

Table 10. *Percentage of relative contribution of taxa feeding primarily on fine particulate organic matter, by river, station, and date*

Stream	Station(s)	Percentage of relative contribution			
		October 1987	May 1988	October 1988	October 1989
Little Platte River	Main	76	72	58	89
	Tributaries	82	66	52	76
Livingston Branch of the Pecatonica River	Main	83	64	82	79
	Tributaries	90	61	78	69
Rattlesnake Creek	Main	58	46	55	53
	Tributaries	55	47	51	48
Sinsinawa River	Main	71	76	69	69
	Tributaries	67	62	69	77

Table 11. *Bray-Curtis dissimilarity coefficients for macroinvertebrate communities in the Little Platte River*

[Maximum dissimilarity = 1; maximum similarity = 0; --, no comparison]

	Spring 1988	Fall 1988	Fall 1989
Fall 1987	0.095	0.514	0.284
Spring 1988	--	.455	.410
Fall 1988	--	--	.419

caddisfly population (filter feeders) (fig. 17). Decreases in the caddisflies were partially offset by increases in the midges, which were at an unusually low abundance in October 1987. Riffle beetles decreased 68 percent, and mayflies increased 125 percent from October 1987 to October 1989 (fig. 17). None of the changes from October 1987 to October 1989, however, were statistically significant at the 5-percent probability level. Mayflies were significantly more abundant in the main study reach than in the tributaries of Livingston Branch during October 1987 and October 1989 (probability is less than 5 percent), and non-insect taxa and shredders (primarily isopods) were more abundant upstream than downstream during the October 1989 sampling period (probability is less than 0.1 percent).

Caddisflies were dominant on all of the sampling dates, except for May 1988, when midges and riffle beetles were dominant (fig. 17). Filter feeders and collector/gatherers dominated among the feeding groups during the study period except for October 1987 when scrapers and shredders were greater than collector/gatherers (fig. 17). The decline in caddisflies and the increase in midges noted in the May 1988 sample are reflected in the corresponding decrease in filter feeders and increase in collector/gatherers (fig. 17). Riffle beetles (and scrapers) composed a significantly greater proportion of the total invertebrates downstream than upstream, and mayflies were proportionately more common within the main study reach than in the tributaries in October 1987 (probability is less than 1 percent). Representation of FPOM processors decreased substantially from October 1987 to May 1988 in both tributaries and the main study reach (table 10), and recovery (as indicated by a return to initial levels) was more

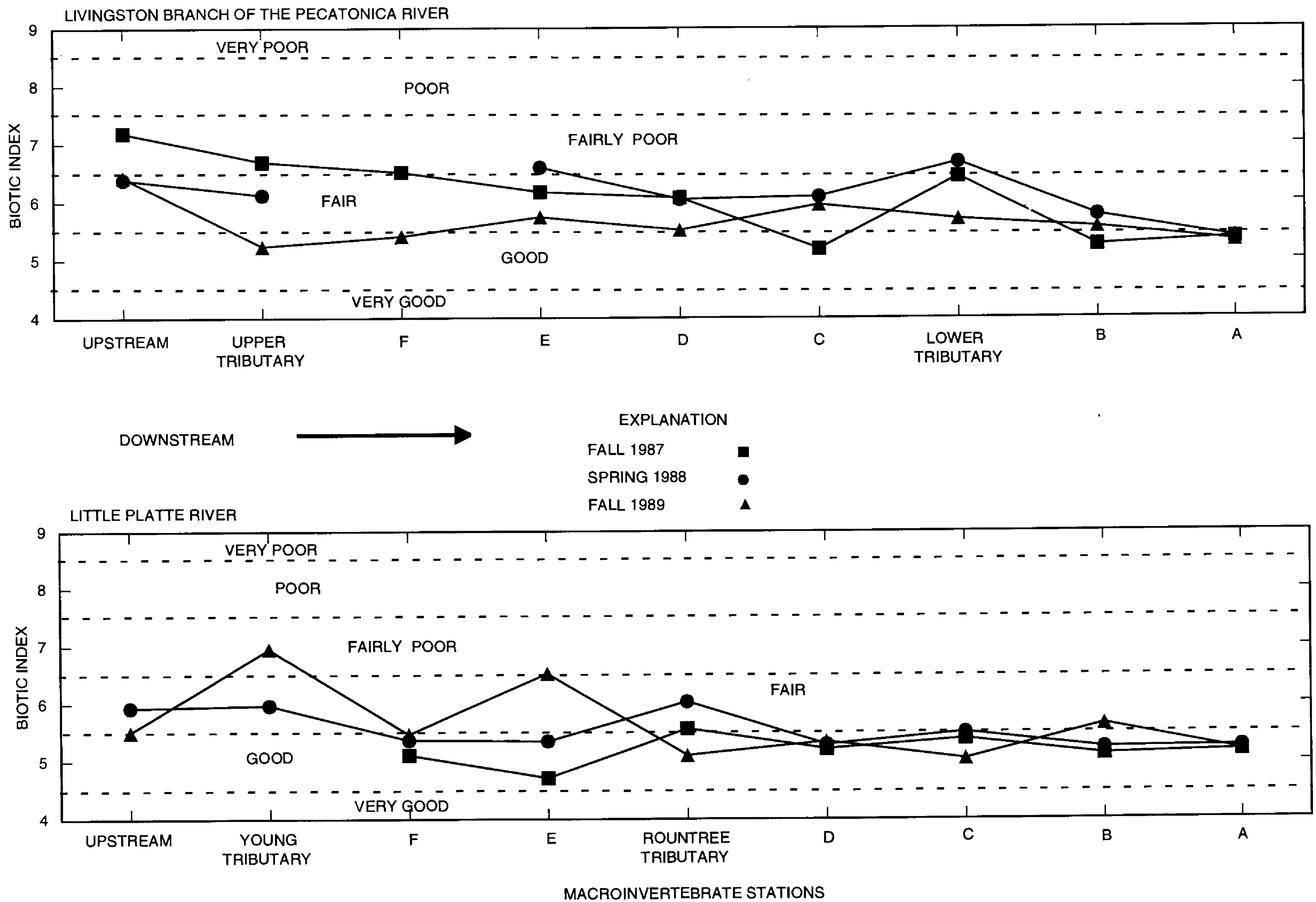

Figure 15. Biotic-index values for macroinvertebrate stations in the Livingston Branch of the Pecatonica River and the Little Platte River, fall 1987, spring 1988, and fall 1989.

Table 12. *Summary of biotic-index assessments for the study streams from Water Resources Research data and Wisconsin Department of Natural Resources, Dodgeville area data*

[DA, Dodgeville area data; WRR, Water Resources Research data; --, no data]

Sampling period or statistic	Little Platte River		Livingston Branch of the Pecatonica River		Rattlesnake Creek		Sinsinawa River	
	DA	WRR	DA	WRR	DA	WRR	DA	WRR
Fall 1987	5.30	5.12	5.95	5.76	5.98	6.62	5.78	6.04
Spring 1988	5.23	5.33	5.38	5.97	5.62	6.84	5.11	6.11
Fall 1988	5.03	--	5.43	--	6.51	--	5.60	--
Spring 1989	5.77	--	5.97	--	5.53	--	5.53	--
Fall 1989	5.55	5.53	5.42	5.58	5.80	5.89	5.72	5.94
Spring 1990	5.53	--	5.75	--	5.89	--	5.45	--
Mean of sampling date	5.40	5.33	5.65	5.77	5.89	6.45	5.60	6.03
Standard deviation	.27	.20	.28	.20	.35	.50	.13	.09
Standard error	.11	.12	.11	.11	.14	.29	.05	.05
Coefficient of variation (in percent)	5	4	5	3	6	8	2	1

complete in the main study reach than in the tributaries by October 1989.

Seasonal dissimilarities in community composition (functional classes) were more pronounced than annual (fall to fall) changes in community composition in Livingston Branch of the Pecatonica River (table 14). The 1989 fall community was more similar to the fall 1987 community than to the fall 1988 community.

Individual BI values ranged from good to fairly poor (fig. 15). Mean Dodgeville area BI values (5.65) indicated fair water quality and corresponded with mean Water Resources Research BI values of 5.77 (fair water quality) (table 12). BI values in tributaries were generally higher (poorer water quality) than BI values in the main study reach (fig. 15 and table 13); however, the upper tributary generally had BI values better than or comparable to the main study reach. Water quality improved downstream during fall 1987 and spring 1988 sampling periods. No spatial trends were apparent during fall 1989 (fig. 15).

Rattlesnake Creek

Fifty-four macroinvertebrate taxa were collected from Rattlesnake Creek and its tributaries during the study. Total taxa richness within the main study reach ranged from 9 to 23 taxa, and mean taxa richness increased slightly (and steadily) from fall 1987 through fall 1989 (fig. 18). EPT taxa richness ranged from 2 to 9, and mean EPT taxa richness was nearly constant during the study (fig. 18).

Mean total macroinvertebrate abundance ranged from 3,420 to 13,200 individuals/m^2 and averaged 7,560 individuals/m^2 for the four sampling dates. Total macroinvertebrate abundance declined by more than 50 percent from October 1987 to October 1989 (fig. 19), but this

Table 13. *Mean biotic-index values by location within study streams and tributaries*

[--, no data]

Stream and date	Tributaries[1], N is variable		Upstream (F-D), N = 3		Downstream (A-C), N = 3		Main stations (A-F), N = 6	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Little Platte River								
Fall 1987	5.56	--	5.01	0.26	5.23	0.14	5.12	0.22
Spring 1988	5.98	0.05	5.34	.04	5.33	.15	5.33	.10
Fall 1989	5.85	.97	5.78	.65	5.29	.31	5.53	.53
Livingston Branch of the Pecatonica River								
Fall 1987	6.77	±.39	6.25	±.23	5.27	.09	5.76	±.56
Spring 1988	6.40	±.28	6.31	.39	5.75	.36	5.97	.44
Fall 1989	5.79	±.60	5.55	.17	5.61	.32	5.58	.23
Rattlesnake Creek								
Fall 1987	5.74	.47	6.97	.54	6.27	.25	6.62	.54
Spring 1988	6.91	.71	6.92	.28	6.76	.40	6.84	.32
Fall 1989	5.87	.06	6.03	.86	5.76	.30	5.89	.60
Sinsinawa River								
Fall 1987	6.22	.32	5.96	.14	6.11	.10	6.04	.14
Spring 1988	6.11	.43	6.22	.12	6.00	.22	6.11	.20
Fall 1989	5.80	.39	5.65	.63	6.21	.28	5.94	.53

[1] Includes upriver station.

change was not statistically significant at the 5-percent probability level primarily because of the variability among the stations within Rattlesnake Creek. The abundances of most invertebrate taxa and functional classes declined from October 1987 to October 1989, but only decreases of midges and collector/gatherers were statistically significant at the 5-percent probability level (fig. 19). Mayflies doubled in abundance from October 1987 to October 1988 and then declined significantly (75 percent) in October 1989 (fig. 19). Midges, total insects, scrapers, and collector/gatherers were significantly less abundant at downstream stations during October 1989 (probability was less than 5 percent). Macroinvertebrate abundances were not significantly different between tributaries and the main study reach (probability was less than 5 percent).

Midges dominated the macroinvertebrate community of Rattlesnake Creek on all sampling dates, and caddisflies, riffle beetles, and mayflies were of secondary importance (fig. 19). Among the functional-feeding classes, a combination of collector/gatherers, filter feeders, and shredders predominated (fig. 19). Taxa that feed primarily on FPOM accounted for approximately 50 percent of the total taxa present on the main stream and tributary streams (table 10).

The temporal display of Bray-Curtis dissimilarity coefficients observed in Rattlesnake Creek probably represents a typical pattern

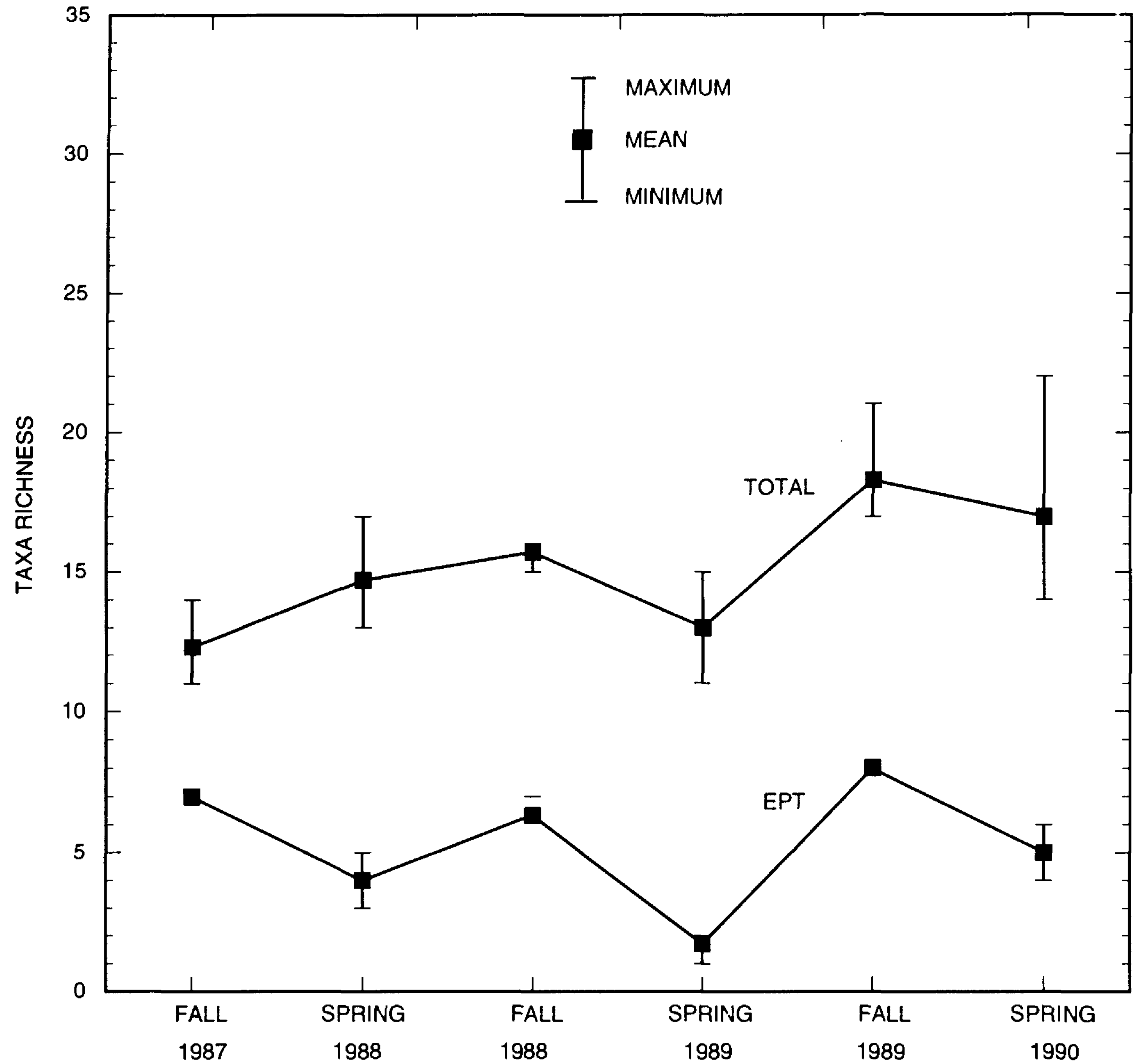

Figure 16. Total taxa richness and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness in the Livingston Branch of the Pecatonica River, fall and spring 1987-90.

(table 15). The moderate amount of dissimilarity noted between fall 1987 and spring 1988 (0.310) and between spring 1988 and fall 1988 (0.344) may represent normal seasonal fluctuations associated with the synchronization of certain taxa to the input and consumption of leaf matter in the fall and winter months. Very little change occurred between fall 1987 and fall 1988 (0.063). The fall 1989 community was moderately dissimilar to the fall 1987 and fall 1988 communities and very dissimilar to the spring 1988 community.

Individual BI values in Rattlesnake Creek ranged from good to poor (fig. 20). Mean BI values collected by the Dodgeville area office (DA) indicated fair water quality (5.89) and BI values for the smaller Water Resources Research (WRR) data set also indicated fair water quality (6.45) (table 12). Mean BI values of tributaries did not differ substantially from BI values of the main study reach (table 13); however, Kuenster Creek had much higher BI values representing poorer water quality than the upstream station during the fall 1987 and spring 1988 (fig. 20).

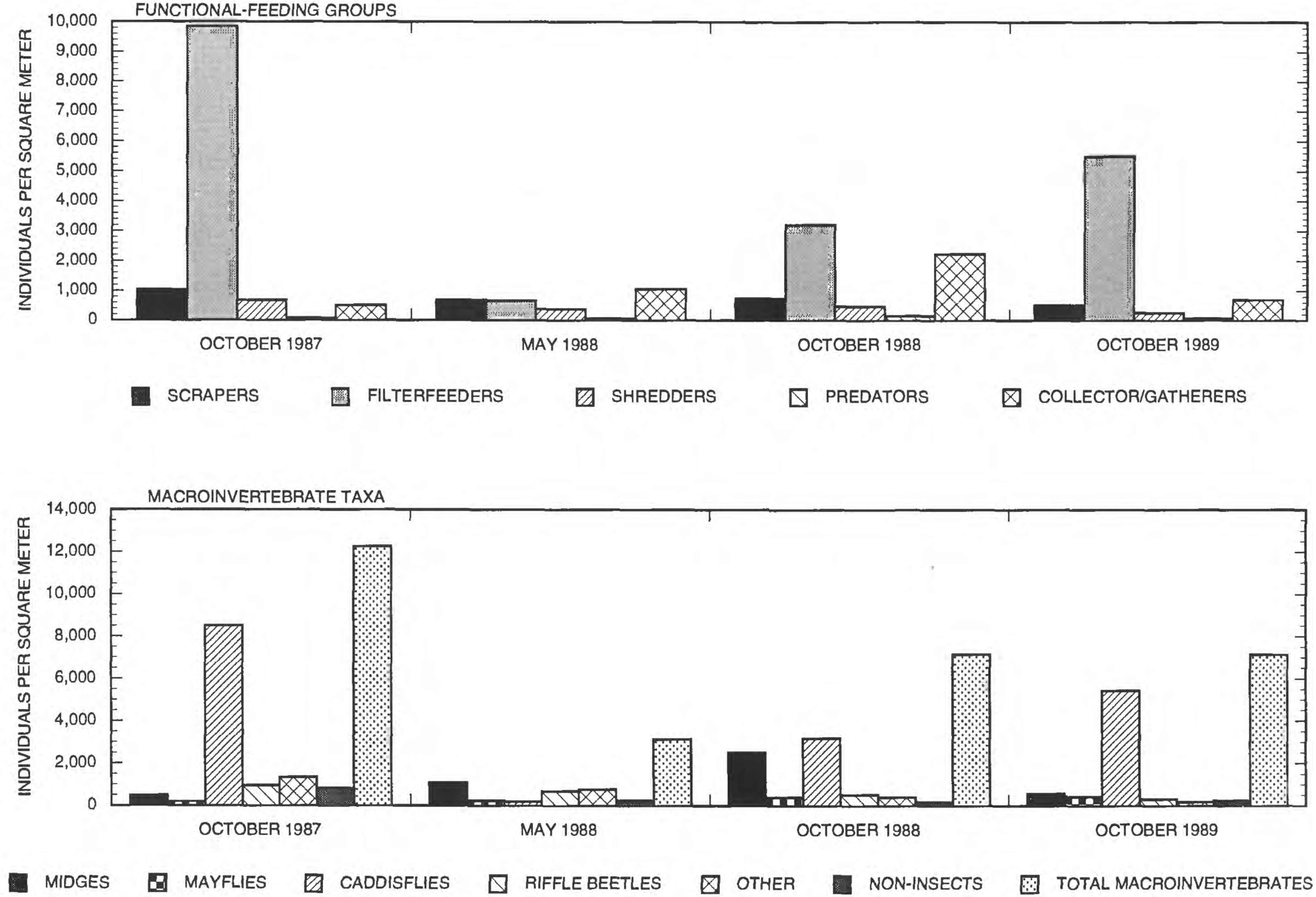

Figure 17. Abundances of macroinvertebrates and functional-feeding classes in the Livingston Branch of the Pecatonica River, October 1987, May 1988, and October 1988 and 1989.

Table 14. *Bray-Curtis dissimilarity coefficients for macroinvertebrate communities in Livingston Branch of the Pecatonica River*

[Maximum dissimilarity = 1; maximum similarity = 0; --, no comparison]

	Spring 1988	Fall 1988	Fall 1989
Fall 1987	0.693	0.472	0.286
Spring 1988	--	.411	.554
Fall 1988	--	--	.313

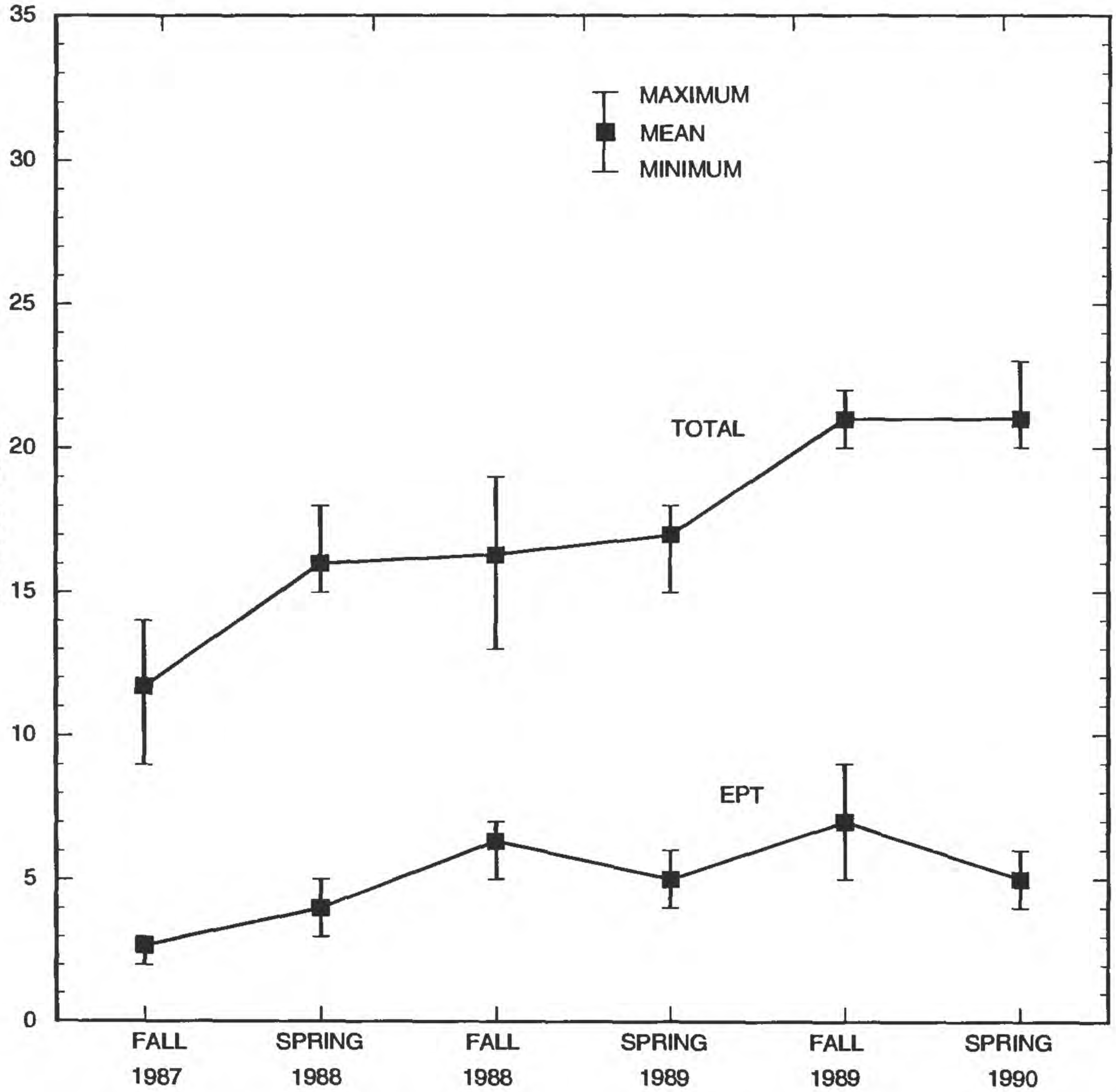

Figure 18. Total taxa richness and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness in Rattlesnake Creek, fall and spring 1987-90.

Water quality, based on BI values, was consistently better at downstream stations than at upstream stations on all dates in Rattlesnake Creek.

Sinsinawa River

Fifty-one taxa were collected from the Sinsinawa River and its tributaries during the study. Total taxa richness ranged from 12 to 22 taxa,

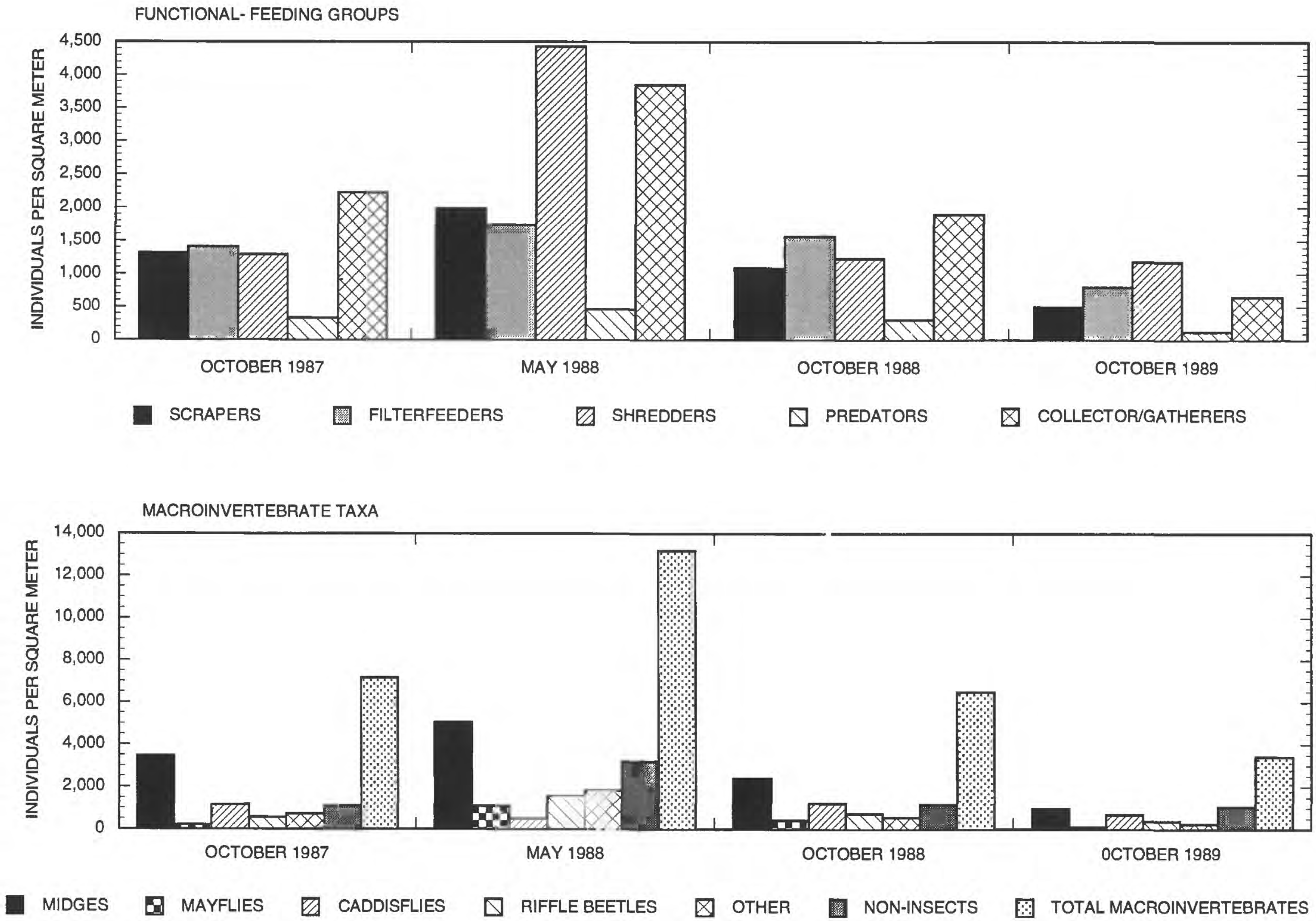

Figure 19. Abundances of macroinvertebrates and functional-feeding classes in Rattlesnake Creek, October 1987, May 1988, and October 1988 and 1989.

Table 15. *Bray-Curtis dissimilarity coefficients for macroinvertebrate communities in Rattlesnake Creek*

[Maximum dissimilarity = 1; maximum similarity = 0; --, no comparison]

	Spring 1988	Fall 1988	Fall 1989
Fall 1987	0.310	0.063	0.338
Spring 1988	--	.344	.587
Fall 1988	--	--	.304

and mean total taxa richness increased by about 50 percent from fall 1987 to fall 1989 (fig. 21). EPT taxa richness ranged from 3 to 10 taxa during the study (fig. 21). Both total and EPT taxa richness declined slightly during the spring 1989 sampling period.

Mean total macroinvertebrate abundance ranged from 2,330 to 7,490 individuals/m^2 and averaged 5,200 individuals/m^2 for the four sampling dates. Total macroinvertebrate abundance decreased by more than 50 percent, and all taxa and functional classes declined from October 1987 to October 1988 (fig. 22); however, none of these declines was statistically significant at the 5-percent probability level. Abundances of most taxa were fully recovered by the fall of 1989. Non-insect taxa were more abundant in tributaries than in the main study reach during October 1988 (probability is less than 5 percent). Riffle beetles (scrapers) and mayflies were more abundant in the main study reach during October 1989 (probability is less than 5 percent). Within the main study reach, total insects and total macroinvertebrates were more abundant at upstream stations during the October 1988 sampling period (probability is less than 5 percent).

Midges and caddisflies (collector/gathers and filter feeders) shared dominance in the Sinsinawa River on most dates (fig. 22), although mayflies and riffle beetles also were present. Except for what might represent a normal increase in abundances of midges in May 1988, the overall community composition of macroinvertebrates in the Sinsinawa River was nearly stable. No significant changes were noted in the percent contribution of any taxa among the fall data (probability is greater than 5 percent). Midges (and shredders) were the most dominant groups of the community composition in tributaries during October 1989 (probability is less than 1 percent). No significant differences in composition were observed between upstream and downstream stations within the main study reach (probability is greater than 5 percent). The relative contribution of FPOM processors did not change appreciably during the study (table 10).

In comparison with the normal seasonal changes in community composition (functional classes), the fall 1988 community was quite dissimilar to the spring 1988 community (table 16). The direction of changes between fall 1987 and fall 1988, and between fall 1988 and fall 1989, were opposite of one another as indicated by the low disparity (0.061) between fall 1987 and fall 1989 communities. Likewise, the fall 1989 community more closely resembled the spring 1988 community than did the fall 1987 community.

Individual BI values in the Sinsinawa River ranged from good to fairly poor (fig. 20). Mean BI values at both the Dodgeville area station and Water Resources Research Section stations indicated fair water quality (table 12). No temporal or spatial trends in BI values or water quality within the Sinsinawa River were detected during the study (table 13 and fig. 20).

Comparisons Among Basins

Taxa richness is one measure of the overall health of the aquatic habitat. The number of different taxa present in a water body generally increases with improvements in water quality. Taxa richness did not differ substantially among the four streams during the study. Initially, total taxa richness was slightly higher in the Little Platte River than in the other

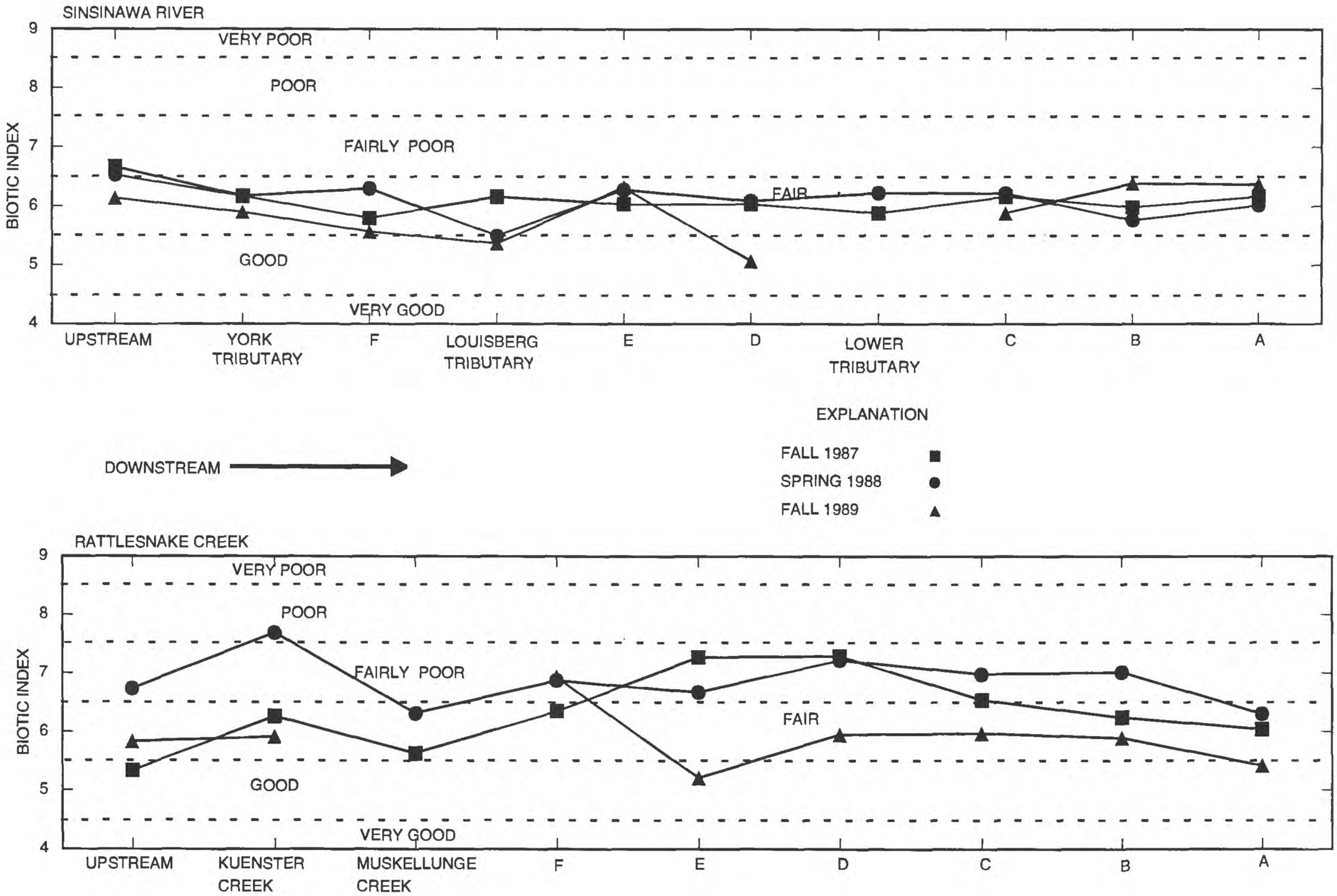

Figure 20. Biotic-index values for macroinvertebrate stations in the Sinsinawa River and Rattlesnake Creek, fall 1987, spring 1988, and fall 1989.

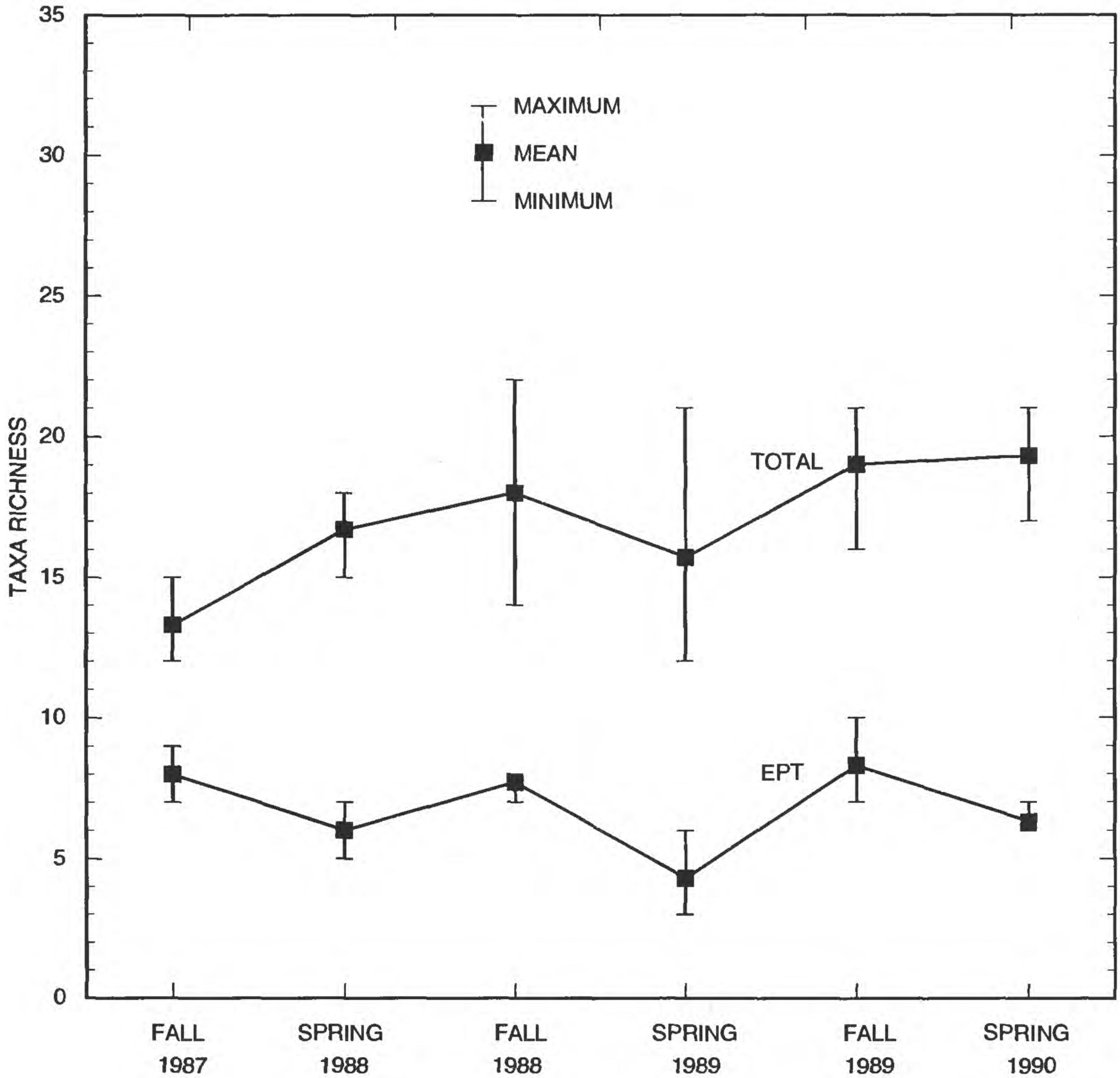

Figure 21. Total taxa richness and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness in the Sinsinawa River, fall and spring 1987-90.

streams, but this disparity disappeared as taxa richness increased in the other three streams throughout the study.

EPT taxa richness generally was quite low in all four streams during the study period. No general trends in EPT taxa were discernible in the four streams.

The relative ranking of mean total macroinvertebrate abundance among streams changed during the study concurrently with temporal fluctuations in abundance. Total macroinvertebrate abundance was significantly higher (probability is less than 5 percent) in the Little Platte River than in either Rattlesnake Creek or the Sinsinawa River in October 1987. By May 1988, total abundance declined substantially in Livingston Branch, but abundances in the other streams increased or stayed relatively high. By October 1989, no significant differences in total abundance existed among the four streams (probability is greater than 5 percent). Few spatial differences were found in total macro-

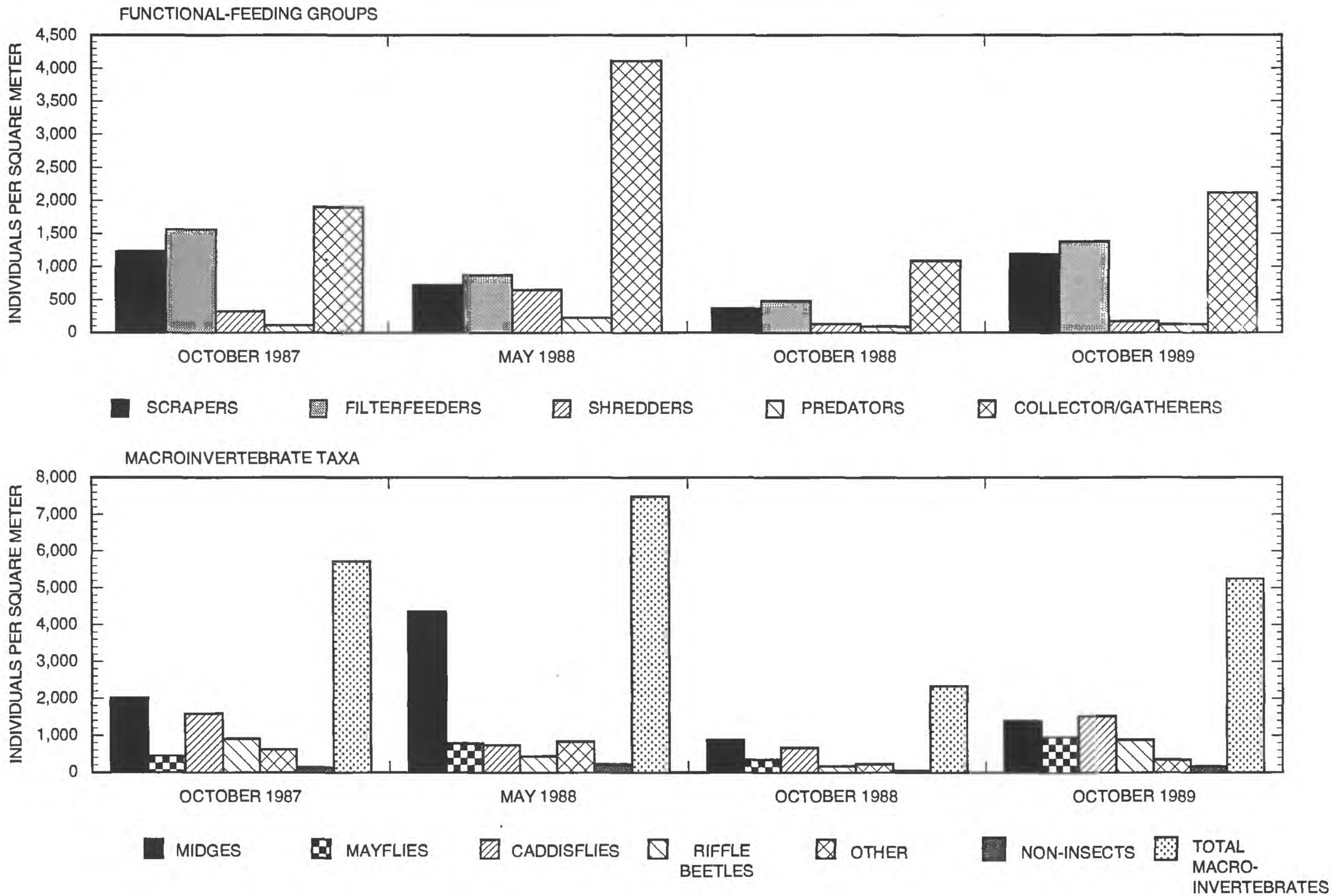

Figure 22. Abundances of macroinvertebrate and functional-feeding classes in the Sinsinawa River, October 1987, May 1988, and October 1988 and 1989.

Table 16. *Bray-Curtis dissimilarity coefficients for macroinvertebrate communities in the Sinsinawa River*

[Maximum dissimilarity = 1; maximum similarity = 0; --, no comparison]

	Spring 1988	Fall 1988	Fall 1989
Fall 1987	0.318	0.409	0.061
Spring 1988	--	.513	.295
Fall 1988	--	--	.397

invertebrate abundances between tributaries and main study reaches or between upstream and downstream stations within the main study reaches.

The abundances of several taxa differed significantly among rivers (probability is less than 5 percent). Livingston Branch generally had fewer midges and more caddisflies than the other streams. Rattlesnake Creek had significantly greater numbers of non-insect taxa and fewer caddisflies than the other streams. The Little Platte River had consistently high numbers of caddisflies, mayflies, and riffle beetles. On the basis of functional-feeding classes, Rattlesnake Creek consistently had more shredders and predators than the other streams. Livingston Branch and the Little Platte River contained more filter feeders than either Rattlesnake Creek or the Sinsinawa River.

Abundances of riffle beetles, scrapers, shredders, collector/gatherers, and total insects decreased significantly from 1987 to 1989 in the Little Platte River (probability is less than 5 percent). Similar but nonsignificant decreases in the abundances of these same taxa in the other streams indicate that some common cause, perhaps related to climate, was responsible. Some taxa displayed distinct seasonal patterns common to all the streams. Midges and shredders (primarily isopods) tended to be most abundant during the spring sampling period, whereas caddisflies generally were most abundant during the fall. These seasonal patterns are probably related to differences in the life-cycle characteristics of the various macroinvertebrate taxa and adaptations to temperature and availability of different food resources.

Patterns among other taxa were distinctly different among the streams. The abundance of midges (and collector/gatherers) increased significantly in Livingston Branch during 1988 and subsequently declined in 1989. Midges (and collector/gatherers) declined significantly from 1987 to 1989 in Rattlesnake Creek. Mayflies increased slightly in 1988 and subsequently decreased significantly in 1989 in Rattlesnake Creek, whereas the reverse trends occurred in the Sinsinawa River. Although almost one-half of the taxa declined from 1987 to 1988 or 1989, the abundance of mayflies peaked in three of the four streams during 1989.

Spatial differences within the main study reach (upstream to downstream) and between the main study reaches and tributaries were common within, but generally inconsistent among, the four streams. Taxa were more abundant at upstream stations 83 percent of the time, but this pattern may have been because of chance alone. The lack of consistency in the patterns of abundance between upstream and downstream locations among dates within rivers indicates that the observed differences were random occurrences and that longitudinal trends within the main study reaches of the four streams were, at most, transient.

The abundance of several macroinvertebrate taxa differed significantly (probability is less than 5 percent) between main study reaches and tributaries in all the streams, except Rattlesnake Creek. Taxa were more abundant in the main study reaches than in tributaries 90 percent of the time. Although the patterns of abundance exhibited by most taxa differed among fall dates in most rivers, mayflies were significantly more abundant in main study reaches than in tributaries 40 percent of the time.

The relative composition of selected taxa and functional-feeding classes of the macroinvertebrate communities varied independently among streams by date. There were, however, a few distinct differences in composition or in temporal trends among the streams. Rattlesnake Creek had a higher percentage of non-insect taxa, shredders, and predators than did the other streams (probability is less than 5 percent). The percentage contribution of midges was relatively constant in Rattlesnake Creek in comparison with wide seasonal fluctuations observed in the other streams. The contribution of filter feeders was consistently higher in Livingston Branch than in Rattlesnake Creek or the Sinsinawa River on all sample dates. The relative contribution of FPOM processors was considerably lower in Rattlesnake Creek than the other streams (table 10). A decrease in the contribution of FPOM taxa in the Little Platte River in October 1988 was not observed in the other streams. The relative contribution of FPOM taxa was relatively constant in main study reaches and tributaries in Rattlesnake Creek and the Sinsinawa River. The contribution of these taxa declined substantially in tributaries on Livingston Branch and fluctuated widely in both the tributaries and the main study sites in the Little Platte River during the study.

Community composition (functional classes), as measured by Bray-Curtis dissimilarity coefficients, exhibited a considerable amount of temporal variability within most rivers (tables 11, 14, 15, 16). If the pattern of changes observed in Rattlesnake Creek from fall 1987 to spring 1988, and from spring 1988 to fall 1988, is assumed to be the norm (that is, some seasonal changes may be expected, but annual changes should be minimal), some conclusions can be drawn from relative comparisons among the streams. The community of the Little Platte River changed very little during the winter of 1987-88 compared with changes in the other rivers. The community of Livingston Branch changed substantially during the same period. Community composition in all of the streams changed moderately during the summer of 1988. The direction of change during the 1988-89 period, relative to the fall 1987 communities, differed among the four streams. Community composition in the Sinsinawa River during the fall of 1989 was quite similar to the fall 1987 community. Communities in the other streams during the fall of 1989 were moderately dissimilar to the fall 1987 communities.

Interpretation of relative comparisons among community compositions of the four rivers (table 17) was complicated by the considerable amount of annual variation in the ref-

Table 17. *Bray-Curtis dissimilarity coefficient matrices based on comparisons of abundances of functional-feeding groups between rivers, by date*

[Maximum dissimilarity = 1; maximum similarity = 0]

Comparison	Fall 1987	Spring 1988	Fall 1988	Fall 1989
Rattlesnake Creek versus Sinsinawa River	0.150	0.330	0.478	0.456
Rattlesnake Creek versus Livingston Branch of the Pecatonica River	.604	.628	.252	.560
Rattlesnake Creek versus Little Platte River	.485	.337	.306	.623
Little Plate River versus Sinsinawa River	.482	.327	.454	.373
Little Platte River versus Livingston Branch of the Pecatonica River	.469	.633	.324	.118
Sinsinawa River versus Livingston Branch of the Pecatonica River	.594	.402	.521	.526

erence river (the Little Platte River, table 11). Because Rattlesnake Creek exhibited the least average amount of change between fall samples among the four rivers (table 15), two sets of relative comparisons were made--one comparison with the Little Platte River as the reference and another using Rattlesnake Creek as the reference. The communities of Rattlesnake Creek and Livingston Branch became more similar to the community of the Little Platte River from fall 1987 to fall 1988, while the community in Sinsinawa River remained more distinct (table 17). The spring 1988 community of Livingston Branch of the Pecatonica River diverged substantially from that of the Little Platte River, while the communities of the other two rivers became more similar to that of the Little Platte River. For this comparison, in which the Little Platte River community represents the best water-quality conditions (best biotic-index values and fisheries), it would appear that the water quality of Rattlesnake Creek and Livingston Branch Creek improved from fall 1987 to fall 1988. If Rattlesnake Creek is the control, the communities of both the Little Platte River and Livingston Branch became more similar to that of Rattlesnake Creek, while the communities of the Sinsinawa River became more dissimilar to that of Rattlesnake Creek.

Water quality, as determined by BI values, generally was better in the Little Platte River than in the other streams from fall 1987 to fall 1988; however, water quality deteriorated in the Little Platte River during the winter of 1988-89. The trends in water quality in Livingston Branch paralleled that of the Little Platte River during the same time period. Water quality remained quite stable in the Sinsinawa River, and water quality improved substantially in Rattlesnake Creek during the same time period. BI values (table 12) in the Sinsinawa River remained quite stable during the study. Rattlesnake Creek had higher BI values (poorer water quality) than the other streams on five of the six sampling dates. The apparent decline in water quality in Rattlesnake Creek during the summer of 1988 was not observed in the other rivers. BI values differed substantially between some tributaries and main study reaches within individual rivers (table 13). With some exceptions, water quality was generally poorer in tributaries than in the main study reaches, and water quality was better at the downstream stations of the main study reaches.

The BI data support the conclusion based on the dissimilarity index comparisons that water quality of the four rivers became more similar from 1987 to 1989. Water quality in the Little Platte River seemed to deteriorate, while water quality in Livingston Branch seemed to improve slightly.

Relation of Hydrology and Water Quality to Macroinvertebrate Populations

Despite the normal amount of spatial and temporal variability in the macroinvertebrate data, some distinct relations were observed among various aspects of the hydrology, water quality, and macroinvertebrates. These relations represent associations and do not necessarily indicate a direct cause-effect relation.

Geomorphic and hydrologic characteristics--such as stream order, watershed size and stream gradients, hydrologic regimes of rivers, and frequency and magnitude of stream discharge--can directly influence macroinvertebrate community composition (Vannote and others, 1980; Poff and Ward, 1989; Pedersen and Perkins, 1986; Resh and others, 1988; Rosillion, 1989; Rae, 1990). The Little Platte River is substantially larger than the other streams, with a watershed size twice that of next largest stream (Rattlesnake Creek) and an average stream width approximately 33 percent wider than Rattlesnake Creek and the Sinsinawa River. Livingston Branch is the smallest of the streams in the study. Stream gradient is high in the two small streams (Livingston Branch and Sinsinawa River). Average annual discharge was much higher in the Little Platte River than the other streams. Large floods can completely devastate macroinvertebrate populations and disrupt community structure if the scouring is of sufficient intensity. Recolonization or recovery may be set back by repeated flooding and destabilization of the streambed. The regularity or periodicity of floods can directly influence community structure. Under normal hydrologic conditions, some differences in the macroinvertebrate communities might have been expected to occur as a consequence of natural differences in the geomorphology and hydrologic regimes of the four streams. As a consequence of the drought, however, fewer storms occurred in all the streams (the greater than 100-year storm in Livingston Branch of the Pecatonica River occurred after the last macroinvertebrate sampling period) and thus an uncharacteristically stable environment for macroinvertebrate development was found. The decreased frequency and intensity of storms may have permitted partial recolonization by uncommon or sensitive taxa. This possibility is substantiated by an observed increase in total taxa richness in three of the four streams. A similar response was not observed in the Little Platte River, possibly because of moderate flooding before the spring sample period in 1989, or because of declines in water quality that offset the benefits of increased hydraulic and substrate stability.

Stream size and discharge also affect bottom substrate, which forms the habitat for most invertebrate taxa. The amount of rock or gravel substrate present will greatly affect the abundance of those taxa that either feed on or live in these coarse substrates. Rock substrate was more common in Rattlesnake Creek and the Little Platte River than in Livingston Branch or the Sinsinawa River. These differences probably account for the greater abundance of scrapers and the presence of a few taxa of mayflies in Rattlesnake Creek and the Little Platte River.

High loadings of suspended solids, silt, and turbidity associated with storms will control the rate and the amount of deposition, which also can greatly influence macroinvertebrate community composition (Roback, 1978). Although some forms of suspended solids serve as food to filter feeders, the quality of suspended solids as a food source varies with the size and composition of particles, the quality of the material, and potential toxics attached to the particles.

Changes in trophic status, which may be occurring (Mason and others, 1990), can affect macroinvertebrate community composition. Nutrients can act either independently or synergistically with inorganic sedimentation to eliminate taxa (Lemly, 1982). Nutrients can support aquatic plant growth, which serve both as habitat and food for macroinvertebrates. Scrapers feed upon benthic diatoms (either on rocks or plants), whereas filter-feeders generally attach themselves to plants and filamentous algae where they feed on suspended particles. Thus, the composition of the periphyton community can directly affect the relative composition of scrapers or filter-feeders in a river. Nutrient inputs of phosphorus from the wastewater-treatment plant at Platteville (or other unidentified point sources) may have supported greater quantities of attached algae (for example, diatoms) that in turn may have contributed to the greater abundances of riffle beetles (and scrapers) in the Little Platte River. The drought may have been responsible for the observed changes in the macroinvertebrate community in the Little Platte River from 1988 to 1989. The lack of dilution water for the wastewater-treatment plant effluent may have contributed to wider diurnal dissolved-oxygen fluctuations (produced by plant photosynthesis and respiration) (Chessman and Robinson, 1987). These subtle differences in dissolved-oxygen regimes may have caused the slight increase observed in BI values (decreased water quality) in the Little Platte River. Before the drought, the Little Platte River had the best water quality of the four rivers (based on biotic index and fisheries) despite also having had high total-phosphorus concentrations.

Competition for available food resources and predator-prey relationships may also have influenced macroinvertebrate community structure (Jacoby, 1987; Gilliam and others, 1989; Reice, 1991). The decreased importance of midges in Livingston Branch may have resulted from interspecific competition between filter feeders and collector/gatherers. Alternatively, this difference may have resulted from decreased sedimentation rates (and greater flushing rates within riffles). Grazing of benthic algae by herbivorous fish species (Stewart, 1987) also may have altered macroinvertebrate community structure within the streams, but the extent of this effect cannot be determined because instream vegetative cover was not measured. Such interspecific competition between fish and macroinvertebrates for vegetative food resources has been demonstrated to be more intense during periods of stable flow (Hart and Robinson, 1990).

Physicochemical differences among streams might produce some of the other dissimilarities in macroinvertebrate communities. The slightly higher base-flow turbidities and suspended solids found in Livingston Branch might account for the decreased importance of predators (reduced visibility) and scrapers (burial by sediments). In contrast, the relatively low base-flow suspended-solids concentrations in Rattlesnake Creek and the Little Platte River possibly account for the greater importance of predators and scrapers in these rivers.

Effects of pesticides and herbicides on macroinvertebrate communities have been well documented in England (Muirhead-Thompson 1987, 1988), but few studies have been done in this country. Monitoring herbicide concentrations in runoff from agricultural lands is difficult because measurable concentrations are transient and short lived (Huckins and others, 1986; Pratt and others, 1988), and detecting a direct cause-and-effect relation between herbicides and macroinvertebrates is difficult because of other factors associated with nonpoint--source runoff. Maximum atrazine concentrations measured in Rattlesnake Creek and the Sinsinawa River exceeded the maximum allowable toxicant concentration of 17.9 µg/L established for dissolved-oxygen response by Pratt and others (1988). Low-level doses of certain herbicides also may adversely affect biota by stimulating algal production (Dewey, 1986), thereby increasing the magnitude of diurnal photosynthesis-respiration dissolved-oxygen regimes (Pratt and others, 1988). Concentrations of pesticides in the Sinsinawa River may have been high enough to affect the macroinvertebrate community.

Dissolved-oxygen reductions may be detrimental to the macroinvertebrate population. Macroinvertebrate taxa differ in their tolerance to low dissolved-oxygen concentrations. Many taxa, particularly stoneflies, mayflies, and caddisflies, are more sensitive (less tolerant) than other taxa to low dissolved-oxygen concentrations. These differences in tolerances form the basis for the use of the EPT richness index and BI in water-quality assessments. The timing of low dissolved-oxygen episodes relative to the life cycle of the particular invertebrate is critical (Resh and others, 1988; Poff and Ward, 1989). Therefore, it is almost inconsequential whether the low dissolved-oxygen concentrations occur during storms or during base flow. If a low dissolved-oxygen episode coincides with the occurrence of a particular sensitive taxa at any time other than the adult stage, the taxa has the possibility of being eliminated. An exception may be those taxa that undergo a period of estivation or diapause (state closely resembling hibernation), an evolutionary adaptation that permits an organism to survive a hazardous period during its life cycle. Dissolved-oxygen regimes were fairly similar among all the streams; however, dissolved-oxygen concentrations were higher in 1987 and lower in 1989 in the Little Platte River than during corresponding sampling periods in the other streams. These subtle differences may have contributed to the observed increase in BI values (deteriorating water quality) during spring 1989 in the Little Platte River.

Many of the temporal changes or differences in macroinvertebrate data detected within and among rivers seemed to indicate asynchronous changes in water quality; however, no specific relations with hydrology or physicochemical water-quality characteristics could be distinguished. For example, although water quality seemed to decline in the Little Platte River and Livingston Branch from fall 1988 through spring 1989 (BI values increased), water quality in Rattlesnake Creek seemed to improve substantially, and water quality in the Sinsinawa River remained stable. This apparent deterioration in water quality in the Little Platte River in spring 1989 was not corroborated by the other metrics. It is not clear whether the increase in macroinvertebrate BI values was related to the apparent decline in dissolved-oxygen regimes noted during 1989 or to the early spring flooding. Neither the spring flooding nor the lower dissolved-oxygen regimes had any apparent effect on taxa richness or other metrics.

Summary

Water quality, based on macroinvertebrate biotic-index data, appeared to be slightly better in the Little Platte River than in the other streams in October 1987. By October 1989, no significant differences in water quality were detectable among the streams. Water quality in Rattlesnake Creek, Livingston Branch, and the Sinsinawa River improved slightly during the drought, probably as the result of increased hydraulic stability coincident to reduced flooding. In contrast, water quality in the Little Platte River deteriorated during the drought, because of dissolved-oxygen reductions caused by reduced capacity of base flow to assimilate and dilute phosphorus concentration from a wastewater-treatment plant in Platteville. Macroinvertebrate composition differed among streams in accordance with differences in stream size, discharge, and the effect of these differences on substrate composition and food-resource pathways. The number of detectable differences in invertebrate abundances among streams decreased from 1987 through 1989, indicating that the streams either became more similar in 1989 or that variability within streams increased in 1989, masking natural differences. Water quality (BI values) and macroinvertebrate abundances were adversely affected in most tributaries; this finding indicates that water-quality problems either originated in headwater areas or were more severe in tributaries than in main river reaches. Herbicides and insecticides may be affecting macroinvertebrate abundances and compositions, but definite conclusions about the effects of pesticides are impossible on the basis of available data.

SMALLMOUTH BASS POPULATIONS

by J.W. Mason[5], J.D. Lyons[6], and R.A. Kerr[7]

Populations in Study Streams

Smallmouth bass (*Micropterus dolomieui*) are the only top carnivorous fish native to many southwestern Wisconsin streams, and they are the primary sport fishery species in the streams they inhabit. Their habitat and water-quality requirements are quite specific (Schneberger, 1972; Edwards, 1982). Smallmouth bass are very sensitive to environmental degradation. They coexist with varying numbers of other fish species in southwestern Wisconsin streams, and, along with several closely associated species, seem to be a good indicator of water quality (Lyons and others, 1988). Changes in population number, age structure, or health of the population can be indicative of water-quality degradation. Results of smallmouth bass population monitoring on the four study streams were used to define the relations among fish populations, hydrology, and water quality.

Little Platte River

The Little Platte River and the Galena River (Forbes, 1989) were apparently the only known streams where serious declines in the smallmouth bass populations had not taken place by the mid-1980's. In 1984, the Little Platte River had a viable smallmouth bass population (R.A. Kerr, Wisconsin Department of Natural Resources, unpublished data, 1985). Therefore, the Little Platte River seemed to be the best choice as the reference stream even though it was larger than the other three streams.

Study of the Little Platte River was intended to provide information on smallmouth bass population dynamics in a stream that was relatively unaffected by water-quality problems. Previous studies of smallmouth bass population in streams in the Driftless Area Ecoregion revealed that populations were characterized by large seasonal and annual variability. The variability was found even in streams where habitat was good or excellent (Brynildson and others, 1959; Brynildson and Truog, 1965; Paragamian, 1984; Forbes, 1985, 1989). The information on past fluctuations of smallmouth bass populations in southwestern Wisconsin streams provides evidence of the dynamic nature of these populations, apparently caused by natural phenomena. With these anticipated natural population swings in the control stream, smallmouth bass population declines caused by water-quality degradation in the other three study streams were to be compared; however, results showed that the Little Platte River had water-quality problems, and extensive smallmouth bass movement into and out of the study reach; therefore, critical evaluation of changes in the smallmouth bass population caused by poor water quality was difficult.

Results of smallmouth bass population surveys (one shocker run) in the Little Platte River from June 1987 through September 1990 are listed in table 18. Surveys made in the summer of 1987 revealed a low population of Age I or older smallmouth bass; by May 1988, however, the population had increased not only because of movement of Age II and older smallmouth bass into the study reach, but also because of the recruitment of a good 1987 year class. The population was largest in September 1988, when the study reach held large numbers of Age 0 and older smallmouth bass. Mason and others (1991) determined that smallmouth bass densities and biomass in 1988 were comparable to the highest population densities and biomass for the region, previously reported by Paragamian (1984) and Forbes (1989). Reproduction was also very successful in 1988 and 1989, and large numbers of Age 0 smallmouth bass were found in September; however, the number of older bass (Age II or greater) in the study reach declined in 1989. The May 1989 survey, which found few smallmouth bass, was preceded by a spring flood on March 11 with a maximum discharge of 2,970 ft^3/s (table 3). The population of Ages I, II, and adult smallmouth bass increased between May and July 1989, because of movement into the study reach. Smallmouth bass tagging studies in 1989 provided further evidence of movement or mortality; only a small number of the fish tagged in spring and summer were still residing in the

[5]Wisconsin Department of Natural Resources
3911 Fish Hatchery Road, Fitchburg, WI 53711.
[6]Wisconsin Department of Natural Resources,
1350 Femrite Drive, Monona, WI 53716.
[7]Wisconsin Department of Natural Resources,
Wilson Nursery, 5350 Hwy. 133 E., Boscobel, WI 53805.

Table 18. *Number of smallmouth bass captured per mile in one shocker run in the Little Platte River*

[--, not determined]

Age	June 1987	July 1987	May 1988	Sept. 1988	May 1989	July 1989	Sept. 1989	Sept. 1990
0	--	--	--	211	--	118	333	17
I	5	3	46	160	19	65	80	126
II	22	9	86	89	14	38	17	64
III or older	5	1	91	42	12	18	12	20
Total	32	13	223	502	45	239	442	227

study reach in September. One adult smallmouth bass tagged in May 1989 was caught by an angler in July, a considerable distance downstream in the Mississippi River. Another was captured more than 40 mi away in the main stem of the Platte River.

Reproductive success was poor in 1990, but large numbers of Age I, II, and III smallmouth bass were found, which represent the strong year classes produced during the 1987-89 period.

Livingston Branch of the Pecatonica River

Population surveys in Livingston Branch from 1958-90, although not continuous, provide the longest record available for a smallmouth bass population in a southwestern Wisconsin stream (fig. 23). Data provided by Brynildson and others (1959), Brynildson and Truog (1965), and Forbes (1985) indicated lower smallmouth bass populations in the early 1980's than were found in the 1960's. Water-quality degradation was believed to have caused the population decline, but no record of the water quality was available.

In June 1987, no smallmouth bass were in the Livingston Branch study reach, and only one smallmouth bass was found in May 1988 (fig. 23). In September 1988, however, 166 young-of-the-year smallmouth bass (Age 0) per mile were caught in the study reach. Whether migratory adults spawned the Age 0 smallmouth bass or the young fish moved into the reach during the summer is unknown. By early May 1989, only 2 percent of the Age 0 smallmouth bass present in September 1988 remained in the study reach. Another strong year class of Age 0 smallmouth bass was found in the study reach in August 1989. In September 1990, few Age 0 smallmouth bass were captured, but the population of Age I and II smallmouth bass was the highest that had been recorded since 1966.

Rattlesnake Creek

Investigations before 1987 showed that Rattlesnake Creek had good to excellent smallmouth bass habitat but that it had a very low population of smallmouth bass (Forbes, 1985; R.A. Kerr, Wisconsin Department of Natural Resources, written commun., 1985; Lyons and others, 1988). Water-quality degradation in the late 1970's and early 1980's was suspected to be the cause of low smallmouth bass populations, but water-quality degradation had never been documented.

The record of smallmouth bass numbers (one shocker run) in the study reach from 1984-90 shows dramatic changes (fig. 24). Starting from a population of two adult smallmouth bass per mile in August 1984, the number caught increased to 367 smallmouth bass per mile by August 1986, largely because of strong year classes in 1984 and 1985. Fish kills during the summer of 1987 decimated the smallmouth bass population. Dead bass were observed after a June storm, and a large-scale fish kill on July 30 devastated the population in the study reach and for a long distance downstream. Investigations after July 30 found many dead smallmouth bass; an early August electrofishing survey showed a 90-percent population reduction from June to August (fig. 24). Recovery began in May

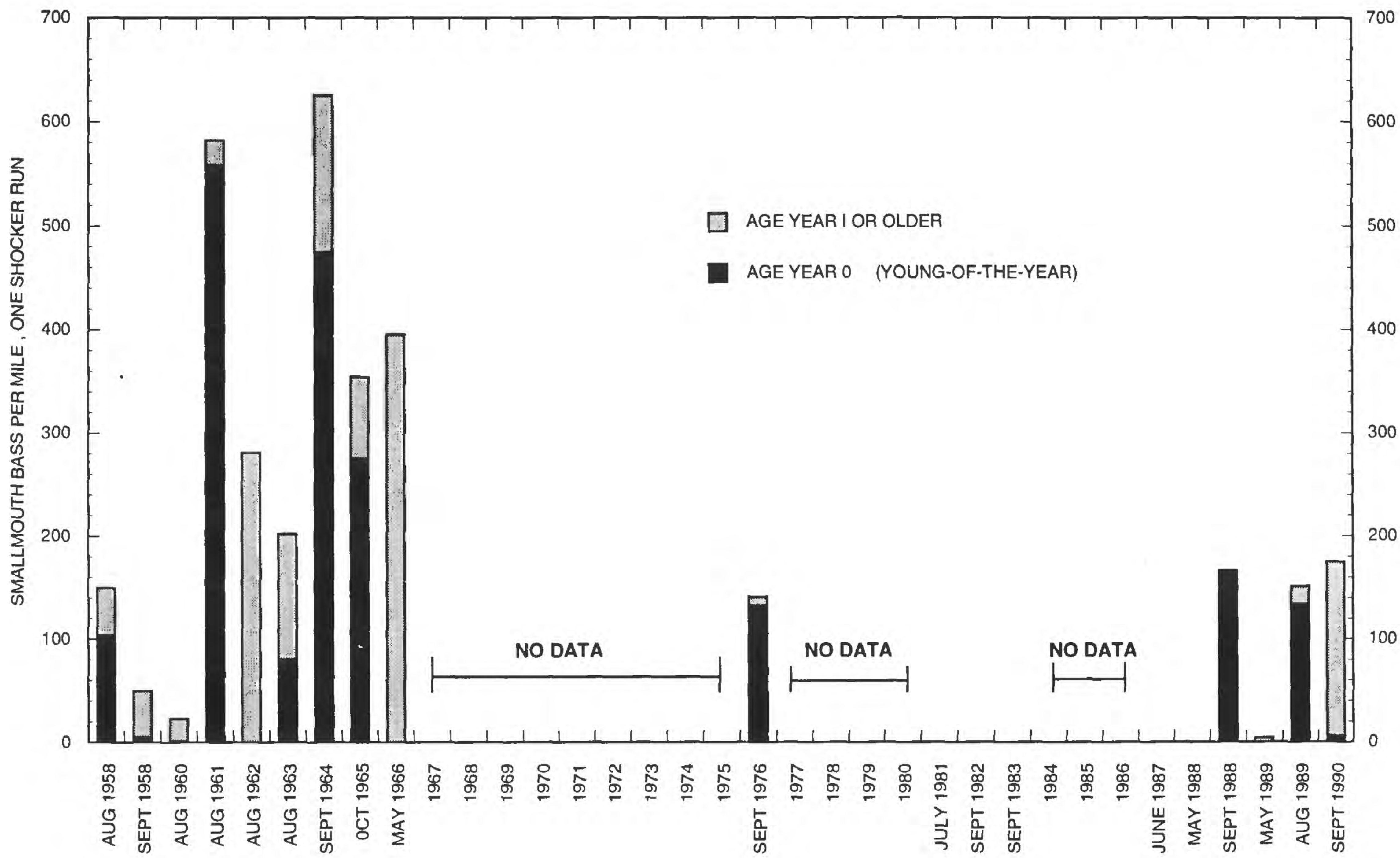

Figure 23. Historical record of smallmouth bass population in the Livingston Branch of the Pecatonica River, August 1958-September 1990. (Data prior to June 1987 from Brynildson and others, 1959; Brynildson and Truog, 1965; and Forbes, 1985.)

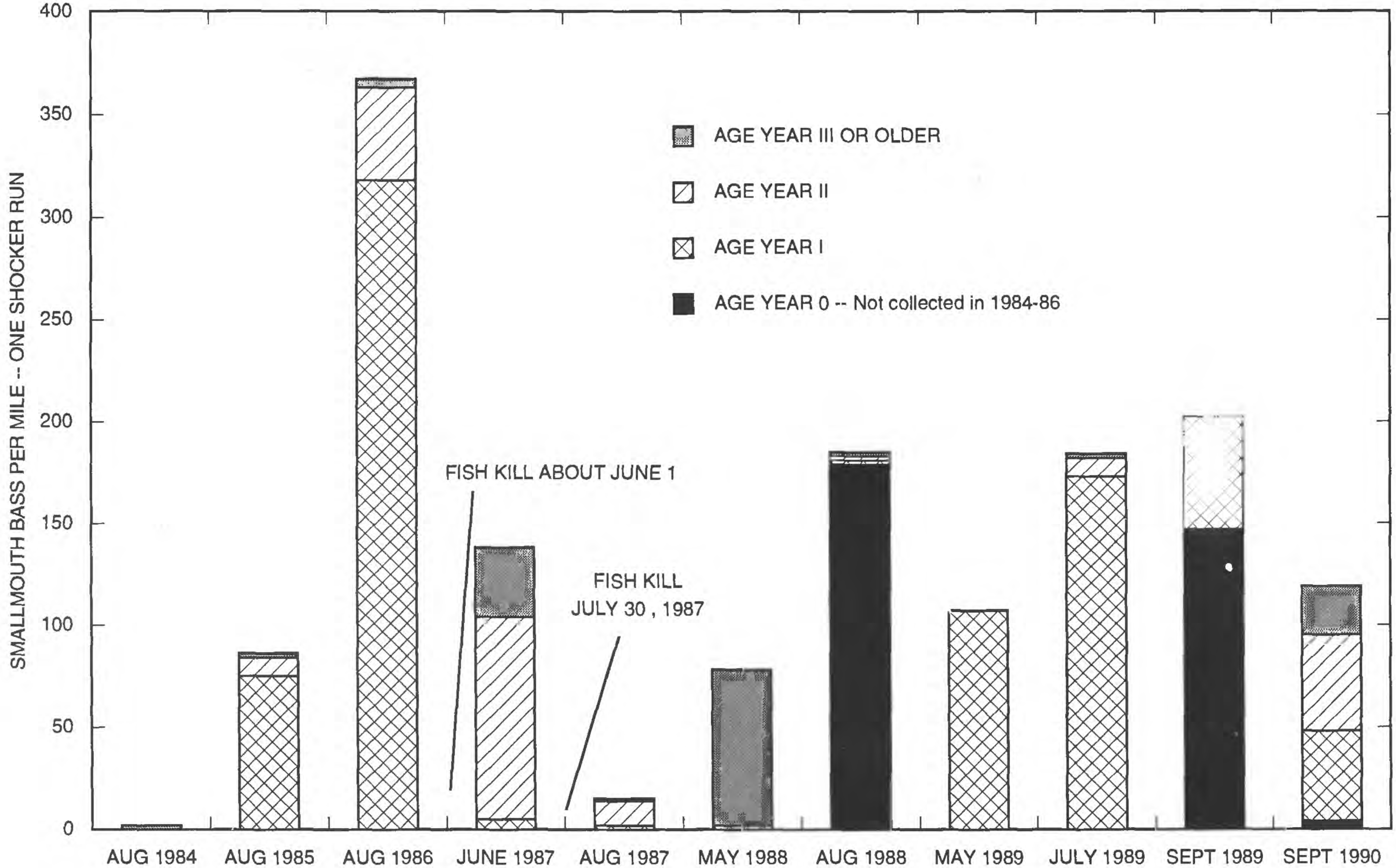

Figure 24. Number of smallmouth bass in the Rattlesnake Creek study reach, 1984-90.

1988 when adult smallmouth bass moved into the study reach. Most of the adults were gone by August 1988, but a strong year class had been produced. The smallmouth bass produced in 1988 continued to reside in the study reach through 1989. Another strong year class was produced in 1989, but the reproductive success was poor in 1990. The September 1990 population was dominated by Age I and II smallmouth bass because of the strong year classes in 1988-89.

Sinsinawa River

By 1987, the Sinsinawa River had a history of fish kills and a reduced smallmouth bass population. The population was eliminated by a discharge from a manure storage facility in 1986 (R.A. Kerr, Wisconsin Department of Natural Resources, unpublished data, 1986). An August 1987 survey upstream from the study reach, and a May 1988 survey in the study reach, showed low numbers of smallmouth bass in the Sinsinawa River (table 19). As a result, the stream was restocked with 350 Age II and III smallmouth bass from the Galena River after the May 1988 electrofishing survey. A strong 1988 year class was found in August 1988, even though a limited fish kill occurred in the study reach before the August survey. Good numbers of yearling bass (Age I smallmouth bass), but no adults, were found in May 1989; however, an exceptionally high number of Age 0 smallmouth bass (1,118 per mile caught in one shocker run) were present in September 1989, along with many large, fast-growing Age I smallmouth bass. The Sinsinawa River smallmouth bass population appeared to be building toward a restored fishery. The September 1990 survey, however, again showed no smallmouth bass in the Sinsinawa River. This absence was probably because of a fish kill. Although not documented by study personnel because data collection had ended, a local landowner reported a major fish kill in late summer 1990, after a storm (J.D. Lyons, Wisconsin Department of Natural Resources, unpublished data, 1990).

Relation of Stream Hydrology to Smallmouth Bass Population

The importance of streamflow in smallmouth bass streams of the Driftless Area Ecoregion during the critical reproductive period was first noted by Cleary (1956). Data on bass year class strength in southwestern Wisconsin and northeastern Iowa streams, and USGS long-term streamflow records, supported the relation between a critical period streamflow and smallmouth bass year class abundance (Mason and others, 1991). Although previous information has established this relation, it can be refined as a predictive tool with additional data. Cleary's (1956) methods, which involve total May and June rainfall in the relation, provides only a rough indication of resulting streamflows and their potential effect on smallmouth bass populations. The amount of runoff produced can vary considerably because of a variety of conditions, such as rainfall intensity, antecedent soil moisture, and ground cover in the drainage basin. Similarly, use of long-term USGS discharge data and smallmouth bass year class strength

Table 19. *Number of smallmouth bass captured per mile in one shocker run in the Sinsinawa River*

[--, not determined]

Age	Aug. 1987	May 1988	Aug. 1988	May 1989	Sept. 1989	Sept. 1990
0	--	--	289	--	1,118	0
I	1	0	0	160	262	0
II	1	0	9	2	0	0
III or more	0	2	38	0	0	0
Total	[1]2	[2]2	336	162	1,380	0

[1] Above study section but indicative of very low population throughout the stream.
[2] Stream stocked with 350 Age II and III smallmouth bass from Galena River after May 1988 electrofishing survey.

data from different drainage basins is not the best method for establishing the relation (Mason and others, 1991). The relation can best be established through continuous streamflow data and reliable information on late summer or fall Age 0 smallmouth bass fingerling numbers collected in the same stream systems. Because of the effects of overland runoff, correlation should be good between stream-stage rises during the critical period and numbers of Age 0 smallmouth bass found later in the year. During the drought years of 1988 and 1989, there was virtually no overland runoff and no significant stage rise in any of the study rivers from mid-May to mid-July (tables 3 and 4). Good numbers of Age 0 smallmouth bass were found in the study rivers in August and September (table 20). Discharge data for 1987 are not complete for any stream, and in Rattlesnake Creek, there was one stage rise of greater than 4.0 ft and later water-quality problems may have affected the number of Age 0 bass caught in the study reach in August. In 1990, however, there were stream-stage rises greater than 1.0 ft during the critical period in all four study streams; stage rises greater than 10 ft and 7 ft were recorded in Livingston Branch and the Little Platte River, respectively (table 4). Population surveys in August and September showed Age 0 smallmouth bass numbers were very low in all the streams (table 20).

The relation between overland-flow runoff during the critical period and smallmouth bass year class strength is further illustrated by figure 25. Use of data collected during 1987-90, available historical WDNR smallmouth population data, and USGS streamflow records on the same stream systems indicate that the data are sharply divided. When overland runoff was more than 0.10 in. from mid-May to mid-July, smallmouth bass reproductive success was severely restricted; three or less Age 0 smallmouth bass per acre were caught in late summer-fall sampling surveys. Conversely, in the years when overland runoff was less than 0.10 in., 32 to 279 Age 0 smallmouth bass per acre were found in late summer or fall.

A Mann-Whitney U test was done on the smallmouth bass population and overland-flow runoff data. The Mann-Whitney U test calculates the probability that two independent samples are from the same sample population (PSTAT, 1989). The null hypothesis is that the number of Age 0 smallmouth bass per acre produced when overland-flow runoff is greater than 0.10 in. is the same as the number produced when overland-flow runoff is less than 0.10 in. The null hypothesis was rejected, and the number of Age 0 smallmouth bass found per acre are significantly different at the 1 percent probability level (p=0.0001) from each other.

Other factors that influence the population of smallmouth bass--for example, predation and food supply--may account for the wide range in numbers of Age 0 smallmouth bass found in late summer or fall during years when streamflow conditions were favorable for smallmouth bass reproduction during the critical period. Effects of low dissolved oxygen associated with rising stage during the critical period have not been determined.

Table 20. *Number of Age 0 smallmouth bass per acre in late summer (August through September 1987-90), one shocker run*

[--, no data available]

Study site	1987	1988	1989	1990
Rattlesnake Creek	0	46	38	1
Little Platte River	--	41	64	3
Sinsinawa River	[1]0	77	297	0
Livingston Branch of the Pecatonica River	--	65	53	2

[1] Above Highway 11, but probably indicative of number in the study area.

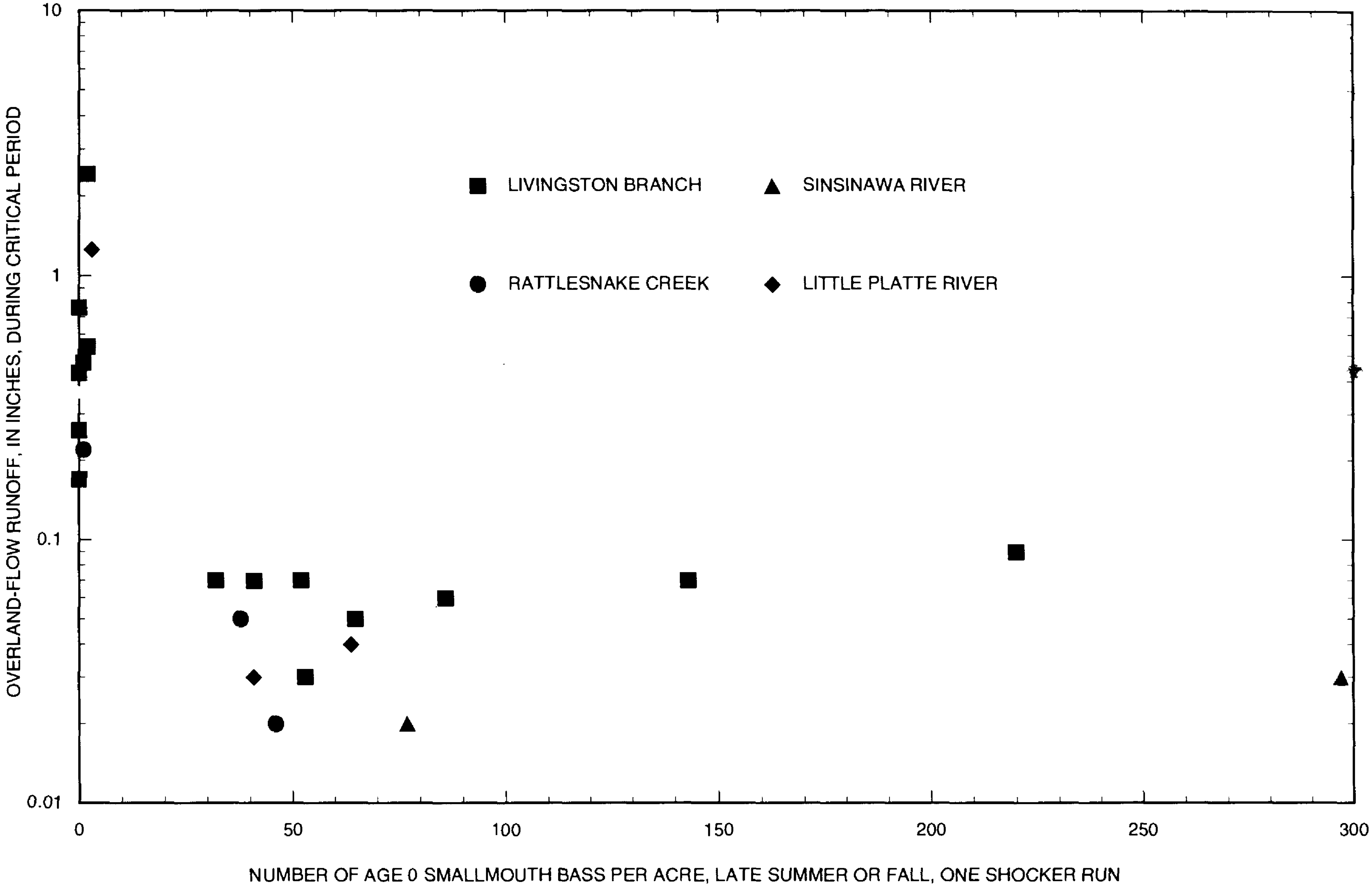

Figure 25. Overland-flow runoff during the critical periods, and number of Age 0 smallmouth bass in the study streams. (Critical period, May 15-July 15, overland-flow runoff from Pecatonica River at Darlington, Rattlesnake Creek near North Andover, Platte River near Rockville, Sinsinawa River at Hazelgreen, Little Platte River near Platteville, and Livingston Branch of the Pecatonica River). Smallmouth bass per acre from Brynildson and others, 1959; Brynildson and Troug, 1965; Forbes, 1985; and this study.

Effects of high stream stage on smallmouth bass populations during winter and early spring were not specifically documented; in some cases, however, the effects seem to have been substantial. For example, a spring flood (peak discharge 2,970 ft^3/s) apparently had a damaging effect on the smallmouth bass population in the Little Platte River on March 11, 1989. A local observer noted a high stage of the stream and reported the runoff smelled strongly of livestock waste. This flood appears to have had a significant effect on the bass population in the study reach. The May 1989 survey of the Little Platte showed a great reduction in population from September 1988 to May 1989 (table 18). The population was much lower in May 1989 than in May 1988. Some smallmouth bass returned to the study reach between May 1989 and July 1989.

Base-flow conditions in southwestern Wisconsin streams affect stream width, depth, and in-stream cover. High base flow appeared to be beneficial to smallmouth bass populations in the study streams, especially for large smallmouth bass that benefit from increased pool depth. In the Little Platte River, base flow was higher in 1988 than in 1989 (table 3), and the population of large smallmouth bass was also higher (table 18). Livingston Branch is the smallest and the shallowest of the study streams. Historically, the smallmouth bass population has consisted of mostly Age 0 and 1. Relatively high base flow in Livingston Branch in the summer of 1990 (table 3) apparently allowed more and larger smallmouth bass to inhabit the stream than had been found there for many years (fig. 23).

Relation of Water Quality to Smallmouth Bass Population

Even though low precipitation and streamflow during the critical period was conducive to good reproductive success, water quality earlier or later in the year may have had a detrimental effect on smallmouth bass populations.

Dissolved Oxygen

When the dissolved-oxygen concentrations found in the study rivers are compared to the criteria for smallmouth bass established by Bulkley (1975), the potential for smallmouth bass mortality existed at times in all four study streams (figs. 6, 8, 10, 12). In addition, there were numerous occasions when sublethal conditions could have forced smallmouth bass to leave the study areas into more favorable habitats. Whether or not Bulkley's (1975) criteria strictly apply in southwestern Wisconsin streams is not known, but they do provide guidelines for examining dissolved-oxygen data. Spoor (1984) found smallmouth bass to be somewhat more tolerant of low dissolved-oxygen concentrations than Bulkley's (1975) criteria indicate.

High streamflows in all four streams during the 1987-90 period reduced dissolved oxygen to less than 1 mg/L; however, smallmouth bass mortality was documented on only two occasions. The July 30, 1987, smallmouth bass mortality in Rattlesnake Creek was directly attributable to the storm that caused low dissolved-oxygen concentrations (fig. 11). The fish kill on the Sinsinawa River in early August 1988, which had only a limited effect on the bass population, also was documented as dissolved oxygen related (fig. 9). The same late July 1987 storm that drastically affected the Rattlesnake Creek smallmouth bass population also caused a severe dissolved-oxygen reduction in Livingston Branch (fig. 9), but no smallmouth bass were in the study reach at that time (fig. 23). Other occurrences of low dissolved-oxygen concentration occurred in Rattlesnake Creek later in 1987 that undoubtedly would have affected the smallmouth bass population had it not already been virtually destroyed. The destruction of the smallmouth bass population in the Sinsinawa River (table 19) during the summer of 1990 could have been caused by dissolved-oxygen reduction, but documentation was impossible because the dissolved-oxygen monitor had been removed.

The effects of some low dissolved-oxygen conditions on smallmouth bass populations in the study rivers was not readily apparent in data from this study. Although the dissolved-oxygen concentration was less than 3 mg/L in Rattlesnake Creek in July and August 1989 (fig. 10), the smallmouth bass population in the study reach was about 200 per mile in both July and September (fig. 24). In September 1989, however, no smallmouth bass older than Age I were found. Likewise, it was impossible to ascertain the effect of the low dissolved-oxygen concentration incident in late August 1990 because the Rattlesnake Creek study reach still had a population of more than 100 smallmouth bass per mile in September 1990. A dissolved-oxygen concentration of less than 2 mg/L was recorded in Livingston Branch in both 1988 and 1990 (fig. 8), yet effects on the smallmouth bass population were not apparent. In September 1990, the population density of Livingston Branch was higher and the number of large smallmouth bass was greater than at any time since the 1960's. Similarly, the data do not show a noticeable effect of low dissolved-oxygen concentrations on the smallmouth bass population in the Little Platte River in 1989 (table 18), even though summer diurnal dissolved-oxygen concentrations during low flow were sometimes less than 3 mg/L, and one storm reduced the dissolved-oxygen concentration to less than 1 mg/L (fig. 7).

In 1988 and 1989, there were many days during the critical period in the four study streams when the dissolved-oxygen concentration was less than 5 mg/L, the minimum smallmouth bass early-life stage requirement given by Bulkley (1975). During both of those years, however, smallmouth bass reproduction was very successful, and strong year classes were produced. Spoor (1984) found most smallmouth larvae could survive dissolved-oxygen concentrations as low as 2.5 mg/L at 20°C and that the effects of low dissolved-oxygen concentrations were greater when water temperatures were 25°C. The study data strongly indicate that smallmouth bass in southwestern Wisconsin streams can survive dissolved-oxygen concentrations that are periodically well below 5 mg/L during their early life stage, possibly because water temperatures are often cool enough to buffer the effects.

Water Temperature

There was no evidence that water temperatures directly affected smallmouth bass populations in the study streams. Cool temperatures and sudden temperature changes during spring and summer are believed to be detrimental to smallmouth bass hatching and fry survival (Webster, 1954; Cleary, 1956); however, examination of long-term temperature records and data on smallmouth bass abundance in southwestern Wisconsin streams showed no clear relation (J.W. Mason, Wisconsin Department of Natural Resources, unpublished data, 1989). Nevertheless, abrupt temperature changes associated with streamstage rises during the critical period may be a factor involved in causing early-life-stage mortality of smallmouth bass during some years.

Temperatures, for the most part, were in the optimum range during the growing season (Edwards, 1982), and bass growth reflected those conditions. Although Livingston Branch had a maximum temperature of 35°C on one occasion in July 1989, the 1989 year class was still relatively strong in the stream. The effect water temperatures, near zero-degree, and stream ice cover for long periods of time is not known; however, cold and ice probably are factors in the apparent movement of smallmouth bass observed out of the study streams during the winter.

Turbidity, Ammonia Nitrogen, Nutrients, and Pesticides

Effects of turbidity and suspended solids on smallmouth bass populations could not be measured in this study. Most of the time, the study rivers were clear, and turbidity and suspended solids posed no problem to smallmouth bass (table 5). During storms, turbidity and suspended-solid concentrations were at times high enough to be potentially damaging. In particular, high turbidity and suspended-solids concentrations during the critical period could have been harmful to smallmouth bass nests or fry in the early-life stage. Other factors, however, such as low dissolved-oxygen concentrations during storms and physical displacement of fish and scouring of the bottom, probably overshadow the effects of high concentrations of turbidity and suspended solids.

Because of the many watershed sources of ammonia nitrogen (crop fertilization, manure from barnyards) and the great quantities known to be carried to southwestern Wisconsin streams during storms, it was reasonable to theorize that toxic concentrations of un-ionized ammonia nitrogen greater than 1.2 to 1.8 mg/L might occur. During the study period, un-ionized ammonia concentrations were greater than the Wisconsin standard of 0.04 mg/L at all of the streams (table 6). The maximum concentration of un-ionized ammonia measured was 0.10 mg/L at Rattlesnake Creek. However, toxic concentrations of un-ionized ammonia nitrogen were not measured in the study streams, and it appears unlikely un-ionized ammonia nitrogen significantly affected smallmouth bass populations.

Nutrients are essential for the growth of plants and animals and are usually found in waters at low concentrations. Excessive nutrient concentrations, however, can eventually degrade the water quality. Base-flow nitrate concentrations have increased in southwestern Wisconsin streams (Mason and others, 1990). Although phosphorus trend data are inconclusive, streams in the region may now be more eutrophic and support more plant growth than they did in the past. The result could be a changed dissolved-oxygen regime in these streams, which in turn may have had a negative effect on smallmouth bass populations.

The total phosphorus discharged from the Platteville sewage-treatment plant may have reduced dissolved-oxygen conditions in the Little Platte River study section (figs. 6, 7). The low-flow phosphorus concentrations in the Little Platte reach were much higher than those in the other study streams. Although direct effects of the added total-phosphorus load on the smallmouth bass population were not readily apparent, this loading represents a deterioration in the environmental quality of the stream as smallmouth bass habitat.

Generally, herbicides are less toxic to smallmouth bass than most insecticides. Only one sample from the Little Platte River had a concentration of 0.44 µg/L of carbofuran (table 9). No other insecticides were detected in any samples. Herbicides, mainly the triazines, were detected with metolachlor having a concentration of 110 µg/L (table 9). These pesticide concentrations are not believed to be toxic to smallmouth bass. However, the possibility of sublethal effects cannot be ruled out.

Summary

Smallmouth bass population surveys in the Little Platte River from June 1987 through September 1990 revealed a low population (13 smallmouth bass per mile) of Age I or older smallmouth bass in July 1987, but by May 1988, the population increased to 223 smallmouth bass per mile. Smallmouth bass populations in the Little Platte River peaked in September 1988 when it was determined that the river held 502 smallmouth bass per mile. In May 1989, only 45 smallmouth bass per mile were found. Reproductive success was poor in 1990 but large numbers of Age I, II, and III smallmouth bass were found, which represented the strong year classes produced during the 1987-89 period.

Historical population surveys indicated that Livingston Branch in the 1950's and 1960's maintained good populations of smallmouth bass. In June 1987, no smallmouth bass were found in the study reach. In September 1988, 166 young-of-the-year smallmouth bass per mile were caught, but only 2 percent of these fish remained in May 1989. Another strong year class of Age 0 smallmouth bass were found in August 1989, but the 1990 year class was very poor.

The population of smallmouth bass in Rattlesnake Creek ranged from 2 adult smallmouth bass per mile in August 1984 to 367 smallmouth bass per mile in August 1986. Fish kills in the summer of 1987 decimated the smallmouth bass population. There was a 90-percent population reduction from June through August 1987. The population began to recover in May 1988. There was good reproductive success in 1988 and 1989. The smallmouth bass population was dominated by Age I and II smallmouth bass.

In the Sinsinawa River, a strong 1988 year class was found in August 1988. In September 1989, 1,118 Age 0 smallmouth bass per mile were caught. In the September 1990 survey, no smallmouth bass were caught.

When overland-flow runoff exceeded 0.10 in., no more than 3 Age 0 smallmouth bass per acre were caught in late summer to fall sampling surveys; whereas, when overland-flow runoff was less than 0.10 in., 32 to 279 Age 0 smallmouth bass per acre were caught in late summer or fall. A Mann-Whitney U test indicated that numbers of Age 0 smallmouth bass per acre were significantly different from each other at the 1-percent probability level ($p=0.0001$).

Water quality had a detrimental effect on the smallmouth bass population. Dissolved oxygen was believed to be the most detrimental water-quality constituent. Smallmouth bass mortality was documented on two occasions because of dissolved-oxygen concentration being reduced to less than 1 mg/L. In 1988 and 1989, there were many days during the critical period in the four study streams when dissolved-oxygen concentration was less than 5 mg/L. Even though the dissolved-oxygen concentration was sometimes less than 5 mg/L in the critical period, the smallmouth bass appeared to survive, possibly because of cool water temperatures that buffered the effects.

There was no evidence of smallmouth bass mortality caused by un-ionized ammonia nitrogen, pesticides or temperature extremes. These water-quality constituents caused no known serious problems in the study streams during 1987-90.

OVERALL CONCLUSIONS

Precipitation and the resulting streamflow can affect the success of smallmouth bass reproduction in any given year. When overland-flow runoff was less than 0.10 in. during the critical reproductive period (mid-May through mid-July), reproductive success was good. When overland-flow runoff exceeded 0.10 in. during the critical period, poor reproductive success resulted. Reproductive success was good in 1988 and 1989, when precipitation was low and overland-flow runoff was less than 0.10 in. in all four basins. Reproductive success was poor in 1987 and 1990, when precipitation was high and overland-flow runoff exceeded 0.10 in. This natural variability of reproductive success and abundance of smallmouth bass will probably continue in the future.

Smallmouth bass populations were sometimes affected by poor water quality even when precipitation and streamflow during the critical period was conducive to good reproductive success. Dissolved-oxygen concentration was determined to be the factor that had the greatest effect on smallmouth bass. Dissolved-oxygen concentrations were occasionally reduced to near or below the minimum concentration considered necessary for survival (1 mg/L) of smallmouth bass at all of the data-collection sites. In two documented cases, low dissolved-oxygen concentrations caused fish kills. Both of these dissolved-oxygen reductions occurred during storms. On numerous days, minimum dissolved-oxygen concentrations were less than 3 mg/L (early-life-stage concentration standard). Smallmouth bass seemed to survive these dissolved-oxygen concentrations that were recorded at or below the reported criteria. The State of Wisconsin 5 mg/L minimum concentration for dissolved oxygen provides an optimum environment for smallmouth bass. Other water-quality properties and constituents measured did not appear to be adversely affecting smallmouth bass or macroinvertebrate populations; however, the influence of pesticides and their effects on smallmouth bass and macroinvertebrates may warrant future studies because of the paucity of pesticide data collected and the difficulty of ascertaining if pesticides were affecting smallmouth bass and macroinvertebrate.

On the basis of macroinvertebrate biotic-index values, water quality seemed to be slightly better in the Little Platte River than in the other rivers at the beginning of the study. By the end of the study, however, no significant differences in water quality were detectable among the rivers. Streamflow periodicity and intensity affected macroinvertebrate populations. During the drought, the number of macroinvertebrate taxa increased because of hydraulic stability caused by reduced flooding. The water quality in the Little Platte River degenerated during the drought, perhaps because of lower dissolved-oxygen concentrations during base-flow periods.

Naturally occurring fluctuations in smallmouth bass populations and extensive smallmouth bass movements made it difficult to attribute changes to water-quality degradation. Previous studies of smallmouth bass populations in Driftless Area streams have demonstrated the dynamic nature of these populations; this study showed that widespread fish movement in and out of given reaches also takes place in streams of the size that were studied. Movement is probably induced by a number of factors such as water temperature, stream depth, and food availability. Therefore, careful and well planned studies would be required in these streams if investigators wish to ascertain cause-and-effect relations and to distinguish between historically normal smallmouth bass populations fluctuations and those directly related to water-quality problems.

REFERENCES CITED

Alabaster, J.S., and Lloyd, R., 1982, Water-quality criteria for freshwater fish (2d ed.): London, Butterworths, 361 p.

Barans, C.A., and Tubb, R.A., 1973, Temperatures selected seasonally by four fishes from western Lake Erie: Journal of the Fisheries Research Board of Canada, v. 30, p. 1697-1703.

Becker, G.C., 1983, Fishes of Wisconsin: Madison, Wis., University of Wisconsin Press, 1052 p.

Berkman, H.E., Rabeni, C.F., and Boyle, T.P., 1986, Biomonitors of stream quality in agricultural areas--fish versus invertebrates: Environmental Management, v. 10, no. 3, p. 413-419.

Bray, J.R., and Curtis, J.T., 1957, An ordination of the upland forest communities of southern Wisconsin: Ecological Monographs, v. 27, p. 325-349.

Broderius, S.R., Drummond, R., Fiandt, J., and Russom, C., 1985, Toxicity of ammonia to early life stages of the smallmouth bass at four pH values: Environmental Toxicology and Chemistry, v. 4, p. 87-96.

Brynildson, C.L., Truog, J., and Esign, A., 1959, The population structure of smallmouth bass in eight southern Wisconsin streams in 1958: Fitchburg, Wis., Wisconsin Department of Natural Resources Investigation Memo Number 248, Southern District Headquarters, 6 p.

Brynildson, C.L., and Truog, J., 1965, The structure of the smallmouth bass population in Livingston Branch, Iowa County, 1958-64: Fitchburg, Wis., Wisconsin Department of Natural Resources Investigation Memo Number 258, Southern District Headquarters, 10 p.

Bulkley, R.V., 1975, Chemical and physical effects on Centrarchid basses, *in* Clepper, Henry, ed., National Symposium on the Biology and Management of the Centrarchid Basses, Tulsa, Okla., February 1976, Proceedings: Washington, D.C., Sport Fishing Institute, p. 286-294

Chapman, G., 1986, Ambient water quality criteria for dissolved oxygen: U.S. Environmental Protection Agency, EPA 440/5-86-003, 46 p.

Cherry, D.S., Dickson, K.L., and Cairns, J., 1975, Temperatures selected and avoided by fish at various acclimation temperatures: Journal of Fisheries Research Board of Canada, v. 32, p. 485-491.

Chessman, B.C., and Robinson, D.P., 1987, Some effects of the 1982-83 drought on water quality and macroinvertebrate fauna in the Lower LaTrobe River, Victoria: Australian Journal of Marine and Freshwater Research, v. 38, p. 289-299.

Cleary, R.E., 1956, Observations on factors affecting smallmouth bass production in Iowa: Journal of Wildlife Management, v. 20, p. 353-359.

Dewey, S.L., 1986, Effects of the herbicide atrazine on aquatic insect community structure and emergence: Ecology, v. 67, no. 1, p. 148-162.

Downing, K.M., and Merkens, J.C., 1955, The influence of dissolved oxygen concentrations on the toxicity of un-ionized ammonia to rainbow trout (*Salmo gairdnerii* Richardson): Annual of Applied Biology, v. 43, p. 243-246.

Edwards, E.A., 1982, Habitat suitability index models--smallmouth bass: U.S. Department of Interior, Fish and Wildlife Service, FWS/-GBS-82-10.35, 47 p.

Ellis, Mel, 1968, Quick Creek smallmouths: Field and Stream, June, 2 p.

Forbes, A.M., 1985, Summary of survey data for smallmouth bass in Wisconsin streams, 1952-80: Wisconsin Department of Natural Resources Research Report 133, 41 p.

____1989, Population dynamics of smallmouth bass (*Micropterus dolomieui*) in the Galena (Fever) River and one of its tributaries: Wisconsin Department of Natural Resources Technical Bulletin 165, 20 p.

Gilliam, J.F., Fraser, D.F., and Sabat, A.M., 1989, Strong effects of foraging minnows on a stream benthic invertebrate community: Ecology, v. 70, no. 2, p. 445-452.

Graczyk, D.J., and Sonzogni, W.C., 1991, Reduction of dissolved oxygen concentration in Wisconsin streams during summer runoff: Journal of Environmental Quality, v. 20, p. 445-451.

Hart, D.D., and Robinson, C.T., 1990, Resource limitation in a stream community--phosphorus enrichment effects on periphyton and grazers: Ecology, v. 71, no. 4, p. 1494-1502.

Hilsenhoff, W.L., 1987, An improved biotic index of organic stream pollution: Journal of the Great Lakes Entomologist, v. 20, no. 1, p. 31-39.

____1988, Seasonal correction factors for the biotic index: Journal of the Great Lakes Entomologist, v. 21, no. 1, p. 9-13.

Hindall, S.M., 1976, Measurement and prediction of sediment yields in Wisconsin streams: U.S. Geological Survey Water-Resources Investigations 54-75, 27 p.

Hole, F.D., 1976, Soils of Wisconsin: Madison, Wis., University of Wisconsin Press, 223 p.

Holmstrom, B.K., and others, 1987-91, Water resources data, Wisconsin, water years 1987-90: U.S. Geological Survey Water-Data Reports WI-87-1 through WI-90-1 (published annually).

Huckins, J.N., Petty, J.D., and England, D.C., 1986, Distribution and impact of trifluralin, atrazine, and fonofos residues in microcosms simulating a northern prairie wetland: Chemosphere, v. 15, no. 5, p. 563-588.

Jacoby, J.M., 1987, Alterations in periphyton characteristics due to grazing in a Cascade foothill stream: Freshwater Biology, v. 18, p. 495-508.

Johnson, W.W., and Finley, M.T., 1980, Handbook of acute toxicity of chemicals to fish and aquatic invertebrates: U.S. Department of Interior, Fish and Wildlife Service Resource Publication 137, 98 p.

Krug, W.R., Conger, D.H., and Gebert, W.A., 1992, Flood-frequency characteristics of Wisconsin streams: U.S. Geological Survey Water-Resources Investigations Report 91-4128, 185 p.

Lackey, R.T., and Hubert, W.L., 1978, Analysis of exploited fish populations, Sea Grant at Virginia Tech, Virginia Polytechnical Institute and State University, 97 p.

Langhurst, R.W., and Shoenike, D.L., 1990, Seasonal migration of smallmouth bass in the Embarrass and Wolf Rivers, Wisconsin: North American Journal of Fisheries Management, v. 10, p. 224-227.

Lemly, A.D., 1982, Modification of benthic insect communities in polluted streams--combined effects of sedimentation and nutrient enrichment: Hydrobiologia, v. 87, p. 229-245.

Linsley, R.K., Jr., Kohler, M.A., and Paulhus, J.L.H., 1975, Hydrology for engineers (2d ed.): New York, McGraw-Hill, 482 p.

Lyons, J.D., Forbes, A.M., and Staggs, M.O., 1988, Fish species assemblages in southwestern Wisconsin streams with implications for smallmouth bass management: Wisconsin Department of Natural Resources Technical Bulletin 161, 25 p.

Mason, J.W., Wegner, G.D., Quinn, G.I., and Lange, E.L., 1990, Nutrient loss via groundwater discharge from small watersheds in southwestern and south-central Wisconsin: Journal of Soil and Water Conservation, v. 45, no. 2, p. 327-331.

Mason, J.W., Graczyk, D.J., and Kerr, R.A., 1991, Effects of runoff on smallmouth bass populations in four southwestern Wisconsin streams *in* Jackson, D., ed., Isd., International Smallmouth Bass Symposium, Nashville, Tennessee, August 1989, Mississippi State University, p. 28-38.

Mathews, Greg, 1984, Coulee smallmouth--plowed under and suffocated: Wisconsin Department of Natural Resources, July-August, 3 p.

Merritt, R.W., and Cummins, K.W., 1984, An introduction to the aquatic insects of North America (2d ed.): Dubuque, Iowa, Kendall and Hunt, 722 p.

Mudrey, M.G., Jr., Brown, B.A., and Greenburg, J.K., 1982, Bedrock geologic map of Wisconsin: Wisconsin Geological and Natural History Survey map, scale 1:1,000,000.

Muirhead-Thompson, R.C., 1987, Pesticide impact on stream fauna with special reference to macroinvertebrates: Cambridge, England, Cambridge University Press, 275 p.

_____1988, Effect of pesticides on the feeding habits of fish: Outlook on Agriculture, v. 17, no. 2, p. 71-76.

Omernik, J.M., and Gallant, A.L., 1988, Ecoregions of the upper midwest states: U.S. Environmental Protection Agency Publication, EPA/600/3-88/037, 56 p.

Paragamian, V.L., 1984, Evaluation of a 12.0 inch minimum length limit on smallmouth bass in the Maquoketa River, Iowa: North American Journal of Fisheries Management, v. 4, p. 507-513.

Pedersen, R., and Perkins, M.A., 1986, The use of benthic invertebrate data for evaluating impacts of urban runoff: Hydrobiologia, v. 139, p. 13-22.

Pflieger, W.L., 1975, Reproduction and survival of smallmouth bass on Courtois Creek, *in* Clepper, Henry, ed., National Symposium on the Biology and Management of the Centrarchid Basses, Tulsa, Okla., February 1976 proceedings: Washington, D.C., Sport Fishing Institute, p. 231-239.

Plafkin, J.L., Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M., 1989, Rapid bioassessment protocols for use in streams and rivers; benthic macroinvertebrates and fish: U.S. Environmental Protection Agency Publication, EPA/444/4-89-001, [variously paged].

Poff, N.L., and Ward, J.V., 1989, Implications of streamflow variability and predictability for lotic community structure--a regional analysis of streamflow patterns: Canadian Journal of Fisheries and Aquatic Science, v. 46, p. 1805-1818.

Pontasch, K.W., and Brusven, M.A., 1988, Diversity and community comparison indices--assessing macroinvertebrate recovery following a gasoline spill: Water Resources, v. 22, no. 5, p. 619-626.

Pratt, J.R., Bowers, N.J., Niederlehner, B.R., and Cairns, John, Jr., 1988, Effects of atrazine on freshwater microbial communities: Archives of Environmental Contamination and Toxicology, v. 17, p. 449-457.

PSTAT, 1989, P-Stat user's manual: 852 p.

Rae, J.G., 1990, The effect of naturally varying discharge rates on the species richness of lotic midges: Hydrobiologia, v. 196, p. 209-216.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow--Volume 1. measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Reice, S.R., 1991, Effects of detritus loading and fish predation on leafpack breakdown and benthic macroinvertebrates in a woodland stream: Journal of the North American Benthological Society, v. 10, no. 1, p. 42-56.

Resh, V.H., Brown, A.V., Covich, A.P., Gurtz, M.E., Li, H.W., Marshall, G.W., Reice, S.R., Sheldon, A.L., Wallace, J.B., and Wissmar, R.C., 1988, The role of disturbance in stream ecology: Journal of the North American Benthological Society, v. 7, no. 4, p. 433-455.

Reynolds, W.W., and Casterlin, M.E., 1976, Thermal preferinda and behavioral thermoregulation in the centrachid fishes, *in* Esch, G.W., and McFarlane, R.W., eds., Thermal

Ecology II Symposium, April 2-5, 1975, Augusta, Ga., Proceedings, p. 185-190.

Roback, S.S., 1978, The effects of thermal effluents and sediments on the insect fauna, *in* Flynn, K.C., and Mason, W.T., eds., Freshwater Potomac--Aquatic Communities and Environmental Stresses Symposium, College Park, Md. Proceedings, January 1977: Rockville, Md., Public Interstate Commission on the Potomac River Basin, p. 119-123.

Rosillion, Dominique, 1989, The influence of abiotic factors and density-dependent mechanisms on between-year variations in a stream invertebrate community: Hydrobiologia, v. 179, p. 25-38.

SAS Institute Inc., 1985, SAS user's guide: Statistics version 5 edition, SAS Institute Inc., Cary, N.C., 956 p.

Schneberger, Edward, 1972, Smallmouth bass life history, ecology and management: Wisconsin Department of Natural Resources Publication 242, 16 p.

Southwestern Wisconsin Regional Planning Commission, 1978, Land use data for Grant County, Wisconsin: Platteville, Wis., 113 p.

Spoor, W.A., 1984, Oxygen requirements of larvae of the smallmouth bass, *micropterus dolomieui*: Journal of Fish Biology, v. 25, p. 587-592.

Stewart, A.J., 1987, Responses of stream algae to grazing minnows and nutrients--a field test for interactions: Oecologia (Berlin), v. 72, p. 1-7.

Thwaites, F.T., 1963, Outline of glacial geology: Ann Arbor, Mich., Edward Brothers, 143 p.

Twidwell, S.R. and Davis, J.R., 1989, An assessment of six least disturbed unclassified Texas streams: Texas Water Commission Report LP 89-04, 243 p.

U.S. Department of Commerce, 1987-90, Climatological data, annual summary: National Oceanic and Atmospheric Administration, v. 92 through v. 95 (published annually).

U.S. Environmental Protection Agency, 1986, Quality criteria for water 1986: U.S. Environmental Protection Agency, EPA 440/5-86-001 (variously paged).

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and Cushing, C.E., 1980, The river continum concept: Canadian Journal of Fisheries and Aquatic Science, v. 37, p. 130-137.

Webster, D.A., 1954, Smallmouth bass, *micropterus dolomieui*, in Cayuga Lake, New York, part 1-life history and environment: Ithaca, N.Y., Cornell University, Agricultural Experiment Station Memoirs, v. 327, 39 p.

Wisconsin Department of Agriculture, Trade, and Consumer Protection, 1985, Wisconsin pesticide use: Madison, Wis., 30 p.

Wisconsin Department of Natural Resources, 1985, Final report of working group on research needs of streams in agricultural watersheds: Madison, Wis., 13 p.