Fish species assemblages in southwestern Wisconsin streams with implications for smallmouth bass management. No. 161 1988

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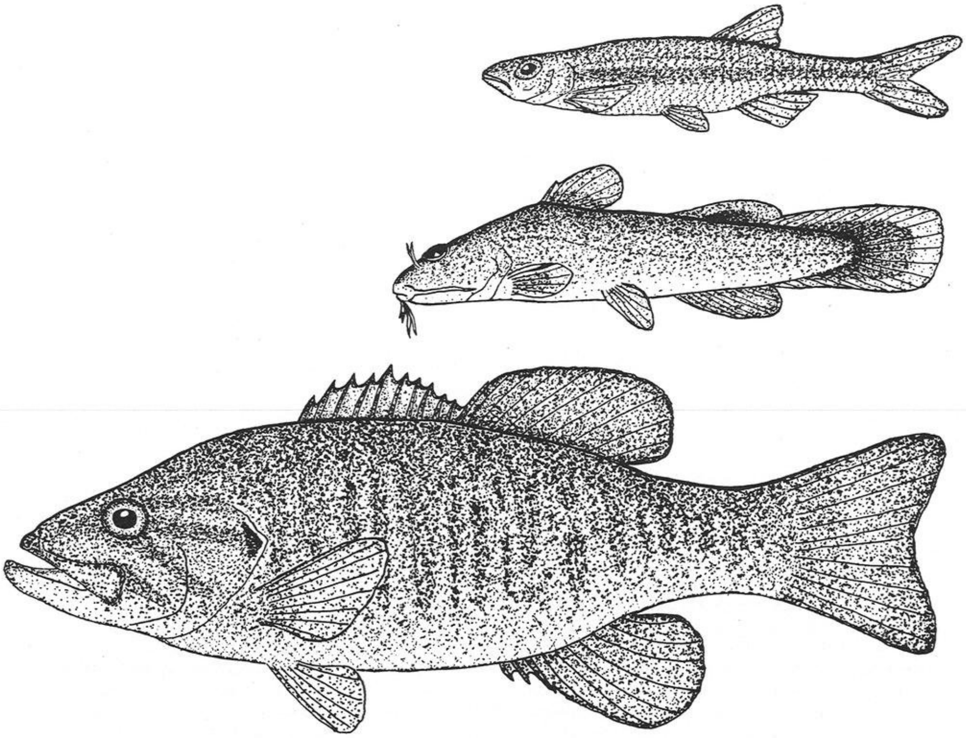
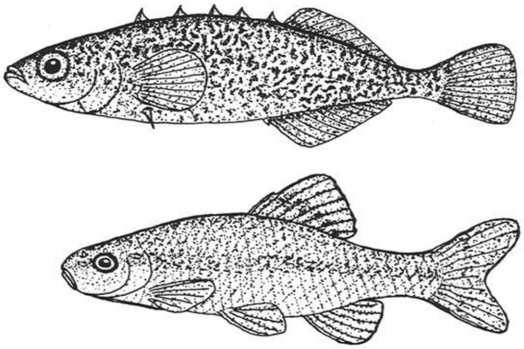


FISH SPECIES ASSEMBLAGES IN SOUTHWESTERN WISCONSIN STREAMS WITH IMPLICATIONS FOR SMALLMOUTH BASS MANAGEMENT



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ABSTRACT

In order to better understand the community ecology of southwestern Wisconsin stream fishes, particularly in relation to the smallmouth bass, we performed a series of univariate and multivariate statistical analyses on data collected in the 1970s by Bureau of Research (Wisconsin Department of Natural Resources) personnel during the statewide Fish Distribution Survey. Fish species assemblages in southwestern Wisconsin streams generally overlapped in species composition and habitat use. One group of fishes was primarily restricted to headwater areas and small tributary streams (less than 10 ft maximum width) and another larger assemblage of fishes was usually found only in the largest streams sampled (30-100 ft maximum width). However, most species were encountered over a wide range of stream sizes, several species were found at greater than two-thirds of all stations sampled, and species composition changed gradually rather than abruptly from headwaters to downstream areas. Smallmouth bass were most closely associated with rosyface shiners and stonecats, and to a lesser extent with hornyhead chubs, sand shiners, and golden redhorse. The presence or absence of most of these species at a location appeared to be a good indication of the potential of that location to support smallmouth bass. Stream size (width and depth), amount of rocky substrate, and water temperature were the most important environmental variables associated with the presence/absence of the smallmouth bass and its associates; all 6 species were most frequently found in portions of streams wider than 20 ft that had more than 40% of the bottom as rocky substrate and water temperatures greater than 68 F (in May and June).

Our results suggest that efforts to restore declining smallmouth bass populations in southwestern Wisconsin streams should focus on integrated management of land use in the watershed, particularly in riparian areas, rather than extensive instream habitat modification.

KEY WORDS: Community ecology, DNR Fish Distribution Survey, multivariate statistical analyses, presence/absence data, environmental gradients, habitat use, agricultural land use, stream size, rocky substrate, water temperature, population declines, *Micropterus dolomieui*.

FISH SPECIES ASSEMBLAGES IN SOUTHWESTERN WISCONSIN STREAMS WITH IMPLICATIONS FOR SMALLMOUTH BASS MANAGEMENT

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INTRODUCTION

In recent years fisheries management concerns have increased over the status of smallmouth bass populations in southwestern Wisconsin streams. Many streams in this region enjoyed excellent reputations for smallmouth bass fishing during the 1950s, but by the 1970s smallmouth bass populations in some of these streams had declined substantially (Forbes 1985 and in press). The causes and consequences of these declines are unclear.

Until now, information on smallmouth bass populations in southwestern Wisconsin streams has been collected primarily through studies focusing solely on the smallmouth bass. Knowledge of the current status of populations is based on short-term fish management surveys to assess abundance and size or age structure in a number of streams (Forbes 1985; Kerr, Wis. Dep. Nat. Resour., unpubl. data), and a longer-term research study of smallmouth bass population dynamics in two streams (Forbes, in press).

By themselves, single species approaches to complex fisheries management problems may give an incomplete picture of the patterns and processes behind those problems. The current difficulty in assessing the causes behind the undesirable status of smallmouth bass fisheries in southwestern Wisconsin streams appears to provide an example of this (Matthews 1984). The complex web of instream habitat, water quality, land use, and biotic interactions in these streams suggests that we must broaden our approach in order to begin to understand the extent, causes, and consequences of smallmouth bass declines. In this paper we attempt to broaden the approach from the single species concept to a community level analysis (Gauch 1982). Using the existing statewide Fish Distribution Survey data base (Fago 1982, 1984, 1985), we examined relationships between southwestern Wisconsin stream fishes and certain environmental factors, and relationships among different species of these fishes.

A community level analysis differs from a population level analysis in that all species present are considered together, rather than individually, and a relatively large number of sampling sites are included, rather than just one or a few. Typically, a community level analysis deals with a limited amount of information (such as presence/absence or relative abundance) about many species at many sites, while a population level analysis deals with a larger amount of information (such as population size, mortality, recruitment, age and size structure, growth, diet, etc.) on a single species at a limited number of sites. Thus, community level and population level analyses are complementary.

There are two main reasons why we chose to examine fish communities, or more accurately, fish assemblages, in southwestern Wisconsin. First, fish assemblages are better indicators of the overall health of aquatic ecosystems than individual fish species or populations (Karr 1981). Data are available on the distribution of all species at many locations in southwestern Wisconsin and on some general environmental characteristics at these locations (Fago 1982, 1985). By using a community level approach to analyze these data, it may be possible to develop insights into the interactions of fishes with their environment and with each other that would not be apparent in studies of individual species. A community level approach may also help to more clearly define the current status of different fish species in the region and help identify factors that are likely to lead to changes in their distribution and abundance.

The second reason we chose to examine fish assemblages and to use a community level approach relates to our interest in smallmouth bass. Population level studies on this species have provided much valuable information (Forbes 1985 and in press), but by themselves cannot explain regionwide patterns in smallmouth bass distribution and abundance. By using a community level approach to identify the typical habitat and associated fishes of the smallmouth bass, and by combining this information with the results of population level studies, we may be better able to understand the observed smallmouth bass declines and to identify the important environmental variables (physical, chemical, and biotic) that must be considered when attempting to restore populations. By identifying an assemblage of species that characteristically associates with the smallmouth bass, a community level approach may help identify indicator species whose presence or absence from a site may reveal the potential of that site to support smallmouth bass.

Our analysis of southwestern Wisconsin fishes focuses on three main questions:

1. Are there well-defined fish assemblages in southwestern Wisconsin? In other words, are there groups of fishes that tend to be found mainly with each other and only rarely with certain other fishes?
2. If they exist, are assemblages found in characteristic habitats (e.g., headwaters, larger rivers, etc.), and is their presence or absence at a site related to specific environmental variables (or groups of variables) such as stream width, depth, substrate, velocity, turbidity, temperature, or agricultural land use in the area?
3. Is there an assemblage of which the smallmouth bass is an important part? If so, what are the characteristics of this assemblage, and in what sort of habitat is it found?

STUDY AREA

Data from the Wisconsin Statewide Fish Distribution Survey (Fago 1984) were used in our analyses of southwestern Wisconsin streams in the Grant, Platte, Galena, and Pecatonica river watersheds (Basins 230 and 223 of Fago 1984; Fig. 1). All four watersheds are in the Mississippi drainage and together encompass about 2,200 miles^2 (Wis. Dep. Nat. Resour. 1978, 1979). The streams range in size from first to fifth in order, but most are second to fourth order.* Figure 2 illustrates some of the streams in this region.

The entire study area is within the driftless area of Wisconsin and remained unglaciated during the most recent Pleistocene glacial advances (Frye et al. 1965). As a result, all four basins have rolling topography and well-developed drainage systems, with few lakes or wetlands. Generally, the northern half of the study area has less topographic relief than the southern half (Knox 1977).

Originally, southwestern Wisconsin was covered by a mixture of prairie, oak savannah, and southern hardwood forest (Curtis 1959), but now much of the land is used for agriculture. About 72% of the land area in the Grant-Platte Basin, which includes the Galena watershed, is now subject to agricultural land use of some sort; this includes croplands, pastures, and farmsteads (Wis. Dep. Nat. Resour. 1978). To the east, the Sugar-Pecatonica Basin consists of 67% cropland and 16% grassland, including pasture (Wis. Dep. Nat. Resour. 1979). The amount of land in row crops, predominantly corn, ranges from 40-50% of the total acreage in the Rattlesnake (Grant watershed), Pats (Galena watershed), Madden (Galena watershed), and Livingston Branch (Pecatonica watershed) subwatersheds (Bachhuber and Forbes, Wis. Dep. Nat. Resour., unpubl. data).

This combination of hilly topography and intensive agricultural land use creates a high potential for runoff of soil, pesticides, nutrients, and animal wastes into streams. The median annual sediment yield to streams in the study area is 200 tons/mile^2, while the statewide median is 80 tons/mile^2 (Wis. Dep. Nat. Resour. 1978). The entire area considered in this study has been designated as part of the critical nonpoint pollution source-area for priority watersheds (Konrad et al. 1985), which indicates that deterioration of water quality due to various agricultural land uses is a major concern.

Several other human activities have affected water quality in streams of southwestern Wisconsin. The region was heavily mined during the 1800s,

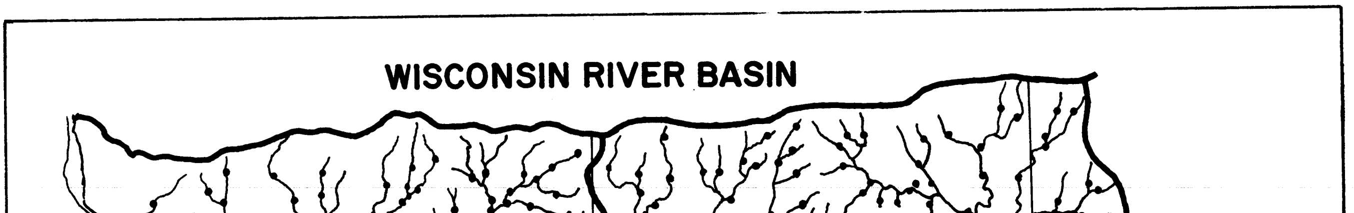

FIGURE 1. *Map of the Grant, Platte, Galena, and Pecatonica drainages in southwestern Wisconsin. Map modified from Fago (1982, 1985). The Grant, Platte, and Galena rivers flow directly into the Mississippi River. The Pecatonica is a part of the Mississippi River Basin, but it does not flow directly into the Mississippi.*

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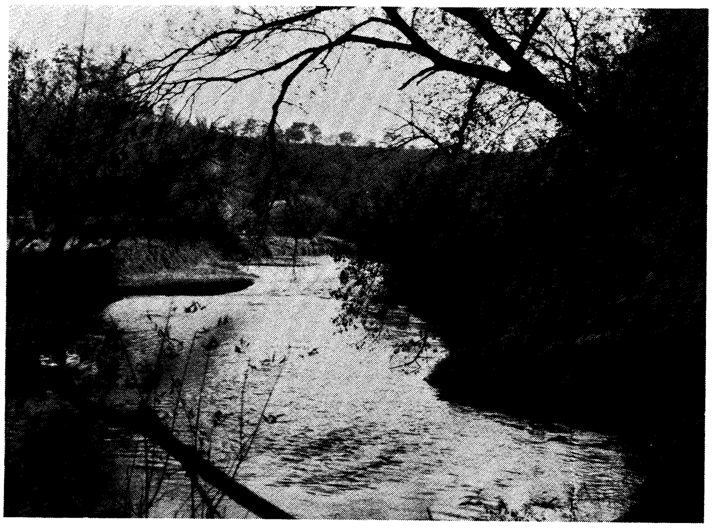
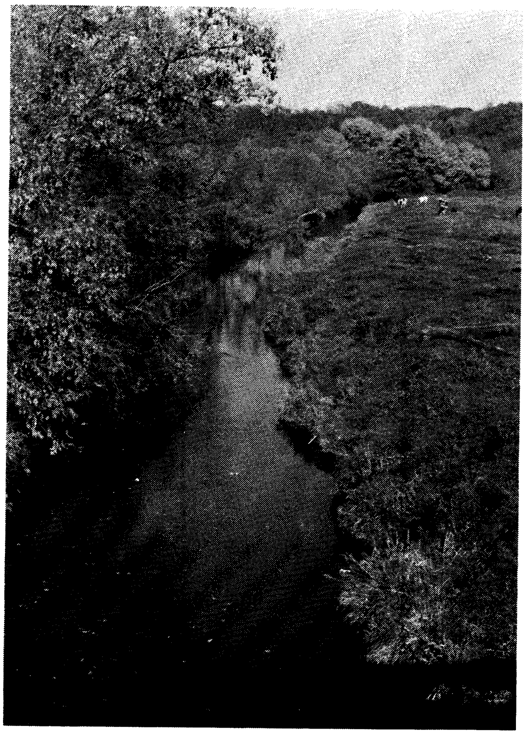
*We used stream order as defined by Strahler (1952, cited in Hughes and Omernick 1981). Briefly, in Strahler's system, a first order stream is a stream that has no tributaries. When 2 first order streams meet they form a second order stream, when 2 second order streams meet they form a third order stream, etc. Thus stream order is a measure of stream size; generally the higher the order, the larger the stream. Strahler's system of determining stream order usually yields much different results than that used by Fago (1984).

and metals leached from abandoned mine tailings limit fish abundance and species richness in a few smaller streams (Wis. Dep. Nat. Resour. 1979, Rahel 1981). Effluent from municipal wastewater treatment plants and small manufacturing companies (primarily cheese factories) also have negative impacts on fishes in some areas (Wis. Dep. Nat. Resour. 1978, 1979). However, there appears to be general agreement that nonpoint sources of agricultural pollution cause the majority of water quality problems in the study area.



Grant River at County Trunk U, Grant County.

Shullsburg Branch at Highway 11, Lafayette County.



Little Platte River north of Dickeyville, Grant County.

FIGURE 2. *Three of the streams included in our analyses.*

METHODS

FISH COLLECTIONS

All fish and environmental data used in this study were collected during the Wisconsin Statewide Fish Distribution Survey from 1976 through 1979 (Fago 1982, 1985). Fish Distribution Survey personnel sampled a large number of discrete stations within each basin, and attempted to capture as large a number and diversity of fish as possible at each station. All fish captured were identified and counted, although if more than 99 individuals of a species were captured at a station, the count was stopped at 99. At each station, the same personnel measured or estimated a variety of environmental parameters when fish were collected. Parameters included channel and flow characteristics, substrate and aquatic plant characteristics, physical and chemical characteristics of the water, and stream bank vegetation and land use. At most stations, most environmental parameters were visually estimated rather than measured (Fago, Wis. Dep. Nat. Resour., pers. comm.) and are thus fairly imprecise. Since we use these parameters to qualitatively describe the general relationships between fish distribution and the environment, we feel that this imprecision is not an obstacle. However, imprecise data are likely to obscure some relationships, so the absence of a statistically significant association does not necessarily mean that a particular environmental parameter does not influence fish distribution. Rather, it means that a relationship could not be detected with the data available. Further details on the procedures used for both fish collections and assessment of environmental parameters are given in Fago (1984).

The data we analyzed were a subset of the total data collected for the survey. Only stream stations sampled in May or June with some type of direct current electroshocker or small-mesh seine were included. A total of 380 stations on 201 streams fit the above criteria. Nearly all of these stations were sampled with electroshockers; seines were used at 9 stations on 3 of the largest streams. Backpack and long-line shockers were used on the smallest streams, stream shockers were used on medium to large streams, and boat-mounted boom shockers were used in the widest and deepest streams. Only species that were present at 5% or more (at least 19) of the stations were included in the analyses (Gauch 1982). Thirty-nine species were included and 46 species excluded by this criterion (Table 1). Most of the excluded species were present at less than 1% (4) of the stations. The following environmental variables were included for each station: minimum, maximum, and mean width; minimum, maximum, and mean depth; velocity; water temperature; turbidity; percentage of rocky substrate (sum of percentages of rubble, gravel, and boulder); and percentage of agricultural land use within 16 ft of each stream bank (sum of percentages of row crops, cut grass, upland pasture, and lowland pasture). We used these composite estimates of rocky substrate and adjacent agricultural land use rather than actual estimates of specific substrate types or land uses because it was sometimes unclear what criteria were used to distinguish between categories. Also, given the qualitative nature of the estimates, we felt that a composite might be more accurate or easier to interpret.

HISTORICAL COMPARISONS

We qualitatively compared data from the Fish Distribution Survey collections with historical (pre-1965) fish collections (Greene 1935, Becker 1966) from southwestern Wisconsin streams in order to identify major changes in fish distribution.

PRESENCE/ABSENCE DATA

Community level analyses can be conducted on presence/absence, relative (proportional) abundance, or absolute (actual number of each species caught) abundance data. Use of each type of data has advantages and disadvantages, and in some cases use of different types can lead to different conclusions.

In this study we restrict our discussion to analyses on presence/absence data since we did not have accurate data on relative and absolute abundances at most stations. Fish Distribution Survey personnel stopped their count of the number of individuals of each species at 99 at each station, so relative and absolute abundances were often unknown. In some cases, the absolute abundance of a species at a station was underestimated by several thousand individuals (Fago, Wis. Dep. Nat. Resour., pers. comm.). Most stations had at least 1 species with a 99 count and about 35% of the species considered had counts of 99 at more than 20% of the stations at which they were encountered. However, in most instances we conducted analyses on all three types of data (presence/absence, proportional and absolute abundance, using 99 as the maximum value), and the results were not qualitatively different.

DATA ANALYSIS

We used one univariate (direct gradient analysis) and several multivariate (cluster analysis, principal components analysis, stepwise multiple regression, and discriminant analysis) techniques to characterize fish assemblages and associated environmental characteristics in southwestern Wisconsin streams.

Direct gradient analysis (DGA) explores the effects of one or two environmental variables on the distribution or abundance of a single species. In our analysis, we plotted the frequency of occurrence for each species (percent of stations at a given environmental value at which a species was present) vs. the following single environmental variables: maximum depth, mean width, water temperature, percentage of rocky substrate, and percentage agricultural land use, and the following pairs of environmental variables: maximum depth and mean width, temperature and mean width, and percentage of agricultural land use and mean width. For all plots maximum depth and mean width were $\log_{10}$ transformed. Visual inspections of the plots were used to identify relationships between variables.

Direct gradient analysis is a useful, relatively simple way to explore possible relationships between environmental parameters and fish distribution or abundance (Gauch 1982). It often facilitates quick identification of the most important variables to consider in subsequent analyses and studies. However, when used alone, DGA has two shortcomings—the influence of more than two environmental variables on distribution or abundance cannot be considered simultaneously, and biotic interactions among species cannot be easily examined.

To overcome these shortcomings, we also conducted a series of multivariate analyses. Multivariate methods consider all environmental parameters or species together, and take into account correlations among them. The multivariate methods described below

TABLE 1. *Common and scientific names of fishes captured from streams in southwestern Wisconsin between 1976 and 1979 by Fago (1982, 1985), and number of stations at which each was captured. Names from Becker (1983).*

Common Name	Scientific Name	Number of Stations*
Species captured at more than 5% of the stations		
Brown trout	*Salmo trutta*	71
Central stoneroller	*Campostoma anomalum*	281
Largescale stoneroller	*Campostoma oligolepis*	23
Common carp	*Cyprinus carpio*	64
Brassy minnow	*Hybognathus hankinsoni*	26
Hornyhead chub	*Nocomis biguttatus*	218
Common shiner	*Notropis cornutus*	289
Bigmouth shiner	*Notropis dorsalis*	139
Ozark minnow	*Notropis nubilus*	25
Rosyface shiner	*Notropis rubellus*	106
Spotfin shiner	*Notropis spilopterus*	85
Sand shiner	*Notropis stramineus*	73
Suckermouth minnow	*Phenacobius mirabilis*	94
Southern redbelly dace	*Phoxinus erythrogaster*	236
Bluntnose minnow	*Pimephales notatus*	281
Fathead minnow	*Pimephales promelas*	114
Blacknose dace	*Rhinichthys atratulus*	60
Longnose dace	*Rhinichthys cataractae*	68
Creek chub	*Semotilus atromaculatus*	301
Quillback	*Carpiodes cyprinus*	38
White sucker	*Catostomus commersoni*	318
Northern hog sucker	*Hypentelium nigricans*	45
Bigmouth buffalo	*Ictiobus cyprinellus*	20
Silver redhorse	*Moxostoma anisurum*	42
Golden redhorse	*Moxostoma erythrurum*	58
Shorthead redhorse	*Moxostoma macrolepidotum*	86
Black bullhead	*Ictalurus melas*	38
Stonecat	*Noturus flavus*	93
Brook stickleback	*Culaea inconstans*	106
Rock bass	*Ambloplites rupestris*	19
Green sunfish	*Lepomis cyanellus*	50
Bluegill	*Lepomis macrochirus*	21
Smallmouth bass	*Micropterus dolomieui*	103
Fantail darter	*Etheostoma flabellare*	248
Johnny darter	*Etheostoma nigrum*	268
Banded darter	*Etheostoma zonale*	39
Slenderhead darter	*Percina phoxocephala*	27
Walleye	*Stizostedion vitreum*	19
Mottled sculpin	*Cottus bairdi*	34
Species captured at less than 5% of the stations		
Silver lamprey**	*Ichthyomyzon unicuspis*	1
American brook lamprey	*Lampetra appendix*	16
Longnose gar**	*Lepisosteus osseus*	3
Shortnose gar**	*Lepisosteus platostomus*	1
Bowfin**	*Amia calva*	1
Gizzard shad	*Dorosoma cepedianum*	1
Goldeye**	*Hiodon alosoides*	1
Mooneye**	*Hiodon tergisus*	1
Rainbow trout	*Salmo gairdneri*	16
Brook trout	*Salvelinus fontinalis*	1
Central mudminnow	*Umbra limi*	4
Grass pickerel**	*Esox americanus*	2
Northern pike	*Esox lucius*	13
Redside dace	*Clinostomus elongatus*	1
Mississippi silvery minnow	*Hybognathus nuchalis*	10
Silver chub	*Hybopsis storeriana*	3
Gravel chub**	*Hybopsis x-punctata*	3
Golden shiner	*Notemigonus crysoleucas*	5
Emerald shiner	*Notropis atherinoides*	17
River shiner	*Notropis blennius*	10
Spottail shiner	*Notropis hudsonius*	4
Mimic shiner**	*Notropis volucellus*	2
Bullhead minnow	*Pimephales vigilax*	6
River carpsucker**	*Carpiodes carpio*	3
Highfin carpsucker**	*Carpiodes velifer*	1
Black buffalo	*Ictiobus niger*	2
Spotted sucker	*Minytrema melanops*	2
Yellow bullhead	*Ictalurus natalis*	7
Brown bullhead	*Ictalurus nebulosus*	1
Channel catfish	*Ictalurus punctatus*	12
Slender madtom	*Noturus exilis*	11
Tadpole madtom	*Noturus gyrinus*	3
Flathead catfish**	*Pylodictus olivaris*	1
Brook silverside**	*Labidesthes sicculus*	1
White bass**	*Morone chrysops*	2
Pumpkinseed**	*Lepomis gibbosus*	3
Orangespotted sunfish	*Lepomis humilis*	13
Largemouth bass	*Micropterus salmoides*	15
White crappie	*Pomoxis annularis*	4
Black crappie	*Pomoxis nigromaculatus*	9
Mud darter	*Etheostoma asprigene*	2
Rainbow darter	*Etheostoma caeruleum*	1
Yellow perch	*Perca flavescens*	2
Logperch	*Percina caprodes*	3
Blackside darter	*Percina maculata*	13
Sauger**	*Stizostedion canadense*	10
Previously reported but not captured in 1976-79		
Goldfish	*Carassius auratus*	0
Red shiner	*Notropis lutrensis*	0
Weed shiner	*Notropis texanus*	0
Blackstripe topminnow	*Fundulus notatus*	0
Iowa darter	*Etheostoma exile*	0

* Maximum number of stations possible was 380.

** These species had not been reported from these basins prior to 1976-79.

are discussed in Gauch (1982) and Pielou (1984). The actual programs that we used are documented in the Statistical Analysis System (SAS) Statistics User Manual (1982).

The first multivariate analysis that we performed on the data was cluster analysis. This analysis grouped sampling stations based on overall similarity in species composition. We specified the number of clusters (groups) of similar stations to be generated. The computer listed the number of stations in each cluster and the proportion of stations within a cluster containing each species. The species most commonly encountered within a cluster can be viewed as a species assemblage.

In our analysis, we concentrated on species that were encountered at least at 25%, 50%, and 75% of the stations within a cluster. We initially ran nonhierarchical and hierarchical (Pielou 1984) cluster analyses that generated two to seven clusters. We found that the nonhierarchical five-cluster output (SAS 1982: PROC FASTCLUS) produced the fewest number of clusters that still retained low within-cluster variability. For this output, we calculated mean environmental parameters for all stations within each cluster to see if differences among clusters in species composition could be related to differences in habitats.

Cluster analysis is often a useful way to identify assemblages, but a potential problem must be considered. That is, the assumption is made that clusters do exist. Cluster analysis places stations into discrete groups when actually species are often distributed along environmental gradients and overlap substantially in distribution with each other. To minimize this problem and to check on the results of cluster analysis, we also ran a principal components analysis (PCA) on the data.

Principal components analysis condensed the presence/absence of the 39 species at all stations into a number of principal components (PC's). From 1-39 PC's could be calculated; we tried several amounts and found the five-PC analysis the most useful. Each PC was a different linear combination of all 39 presences/absences which minimized the variance in the data. Those species that explained a relatively large fraction of the variance in the species' presence/absence correlation matrix got a large loading (positive or negative), while those that explained little got a loading near zero. We assessed whether a species' contribution to a PC was statistically significant by correlating the species' original presence/absence at a station with the PC's score (see below) for that station (Johnson and Wichern 1982).

We used PCA to identify stations that had similar assemblages. Each station received a score for each PC, which was calculated by multiplying each species' presence/absence (i.e., 1 or 0) at that station by that species' loading on the PC, and then summing the resultant product for all species. The scores for each station on each possible pair of PC's were then plotted. Stations (points) that were close to each other in these plots had similar assemblages, while those that were far apart had dissimilar assemblages. By examining these plots, we were also able to determine if there were distinct groups of stations, and if so, whether these groups corresponded well to the groups generated with cluster analysis.

While our PC's were based on species, it was possible to determine the mean environmental characteristics of stations that had a high score on a particular PC, and thus indirectly determine the typical habitats of different assemblages. To do this, we used stepwise multiple regression analysis (SAS 1982: MAXR method), with PC scores as dependent variables and environmental parameters as independent variables.

Both cluster analysis and PCA are useful for identifying assemblage types, but rely on qualitative assessments of the specific and most important ways in which assemblages differ, and reveal little about how stations that contain a specific species differ from those stations from which that species is absent. To quantitatively explore these sorts of differences, we used discriminant analysis, in which linear combinations of environmental or species variables known as discriminant functions are used to separate previously defined groups of stations.

When stations in different groups overlap substantially in species composition or environmental characteristics, discriminant analysis will misclassify a relatively large number of stations. That is, it will predict that a station should belong to one group when it actually belongs to another. The percentage of stations correctly classified is a way to assess the usefulness of the discriminant analysis. Since a certain fraction are likely to be correctly classified merely by chance, we used the Kappa statistic (Titus et al. 1984) to determine if the percentage correctly classified was statistically significant.

In this study, we performed discriminant analysis on the clusters generated by the cluster analysis, and on stations that had smallmouth bass and stations that did not.

RESULTS

HISTORICAL CHANGES

During the Wisconsin Statewide Fish Distribution Survey, 85 species were captured from the streams considered in this study (Table 1; Fago 1982, 1985). Two species, brook trout and rainbow trout, probably persist because of stocking (Fago 1982) and five species previously reported from these streams were not taken (Table 1). None of these 7 species were ever widely distributed or numerous in the study streams. Sixteen of the 85 species captured during the survey had not previously been reported from the study streams (Table 1; Fago 1982, 1985), but none of the 16 were common or widely distributed.

Only 2 species, longnose dace and fantail darter, appear to have substantially extended their ranges in streams of southwestern Wisconsin. Longnose dace were absent from southwestern Wisconsin prior to the 1930s (Greene 1935). They had moved into extreme southwestern Wisconsin by the early 1960s (Becker 1966) and have since become widespread in the Grant and Platte drainages. They are still uncommon in the Galena drainage and absent from the Pecatonica drainage (Fago 1982, 1985). The increase in fantail darter distribution has been less extensive. Apparently, fantail darters have always been present in the region (Greene 1935), but they have entered and moved up a number of new streams in the Grant and Platte drainages since the 1960s (Becker 1966, Fago 1985). Collections from Rattlesnake Creek, a tributary of the Grant River, during 1984 and 1986 suggested that fantail darters have increased in distribution and abundance in that stream since the 1970s (Forbes and Lyons, unpubl. data).

DIRECT GRADIENT ANALYSIS (DGA)

Through DGA, we were able to assign each species to one of four groups based on their relationship to individual environmental variables (Table 2). The four groups consisted of those species that had no obvious relationship to the environmental parameter, those that had a negative relationship, those that had a positive relationship, and those that were most frequently encountered at intermediate values of the parameter. An example of a species in each group and its relationship to $\log_{10}$ average width is shown in Figure 3.

The distribution of most species was related to average stream width and depth (Table 2). Among the 30 most frequently encountered species (9 of the 39 species considered in other analyses were too limited in distribution for DGA), 25 (83%) showed an obvious relation to average stream width. Of these 25, 5 most frequently occurred at narrow stream widths (less than 10 ft), 17 (including smallmouth bass) most frequently occurred at wide stream widths (more than 25 ft), and 3 most frequently occurred at intermediate widths (10-25 ft). In most cases, the same species showed similar associations with maximum depth, i.e., species most frequently encountered at narrow widths were also most frequently encountered at shallow depths (less than 2 ft).

The other environmental variables analyzed were also related to the distribution of many species (Table 2). For the percentage of rocky substrate, 20

TABLE 2. *Direct gradient analysis of the 30 most common fishes on five environmental parameters. Associations were determined by eye; slope, shape, and fit vary within each category.*

Species	Environmental Parameter				
	Avg. Width (Log_{10})	Max. Depth (Log_{10})	Rocky Substrate (%)	Agricultural Land (%)	Water Temperature
Central stoneroller	No*	–	+	+	No
Common carp	+	+	–	I	+
Hornyhead chub	+	+	+	No	+
Common shiner	+	No	+	No	+
Bigmouth shiner	I	No	No	+	No
Rosyface shiner	+	+	No	–	+
Spotfin shiner	+	+	No	–	No
Sand shiner	+	+	No	–	+
Suckermouth minnow	+	+	+	No	+
S. redbelly dace	–	–	+	+	No
Bluntnose minnow	No	No	+	No	No
Fathead minnow	–	–	No	+	–
Blacknose dace	–	–	+	No	–
Longnose dace	No	No	+	No	No
Creek chub	–	–	+	+	–
Quillback	+	+	–	–	+
White sucker	No	No	No	No	No
N. hog sucker	I	No	No	–	+
Bigmouth buffalo	+	+	–	–	+
Silver redhorse	+	+	–	–	+
Golden redhorse	+	+	–	–	+
Shorthead redhorse	+	+	–	–	+
Stonecat	+	+	+	–	+
Brook stickleback	–	–	–	+	–
Green sunfish	+	+	No	No	No
Smallmouth bass	+	+	No	–	+
Fantail darter	No	No	+	+	+
Johnny darter	I	–	+	+	No
Banded darter	+	No	No	No	+
Slenderhead darter	+	No	No	No	+

* No = No obvious relationship.
– = Negative relationship.
\+ = Positive relationship.
I = Most frequently encountered at intermediate values of parameter.

species (67%) had an association (smallmouth bass were positively associated), and for percentage of agricultural land along the stream banks, 20 species (67%) had an association (smallmouth bass were negatively associated). Twenty-one species (70%) had an association with temperature. Smallmouth bass were positively associated and, along with 14 other species, were never captured during May and June in water below 50 F.

Bivariate plots indicated that several species were most likely to be encountered in areas with certain combinations of environmental characteristics. An example of one of these plots is shown in Figure 4. Blacknose dace were most commonly found in narrow, rocky areas, while brook sticklebacks were usually encountered in narrow areas with little rocky substrate. Common carp, quillbacks, and bigmouth buffalos were mainly found in wide areas with little rocky substrate. Central stonerollers were found at all widths but mainly at shallow depths, while banded and slenderhead darters were most commonly encountered at wide and shallow stream areas. Fathead minnows were most frequently captured in narrow areas surrounded by areas with high adjacent agricultural land use, while northern hog suckers, bigmouth buffalos, and golden, silver, and shorthead redhorse were most likely to be encountered in wide areas with relatively little adjacent agricultural development. Fourteen species (including smallmouth bass) were primarily captured only in wide areas with high water temperatures.

Some of the DGA relationships between species distribution and environmental characteristics may not have been real. Instead, they may have been artifacts of intercorrelations among environmental variables. For example, smallmouth bass frequency of occurrence was positively associated with average width, maximum depth, water temperature, and percentage rocky substrate and negatively associated with percentage of agricultural land along the stream banks. However, over all stations average width was positively correlated with maximum depth and water temperature (r = 0.61 and 0.19; $P < 0.0001$ and 0.001, respectively), while percentage of agricultural land along the stream banks was negatively correlated with average width, maximum depth, and water temperature (r = 0.33, 0.19, and 0.15; $P < 0.0001$, 0.001, and 0.015, respectively). Multivariate analyses (cluster analyses, etc.) take into account intercorrelations among variables and help clarify which variables are actually important biologically.

CLUSTER ANALYSIS

Stations in three of the five clusters generated by cluster analysis had substantial similarities in species composition (Table 3). When only species present at 75% or more of the stations within a cluster were considered, Cluster One had 6 species in common with Cluster Two and 4 in common with Cluster Three, while Cluster Three had 6 in common with Cluster Two. Eight species — central stoneroller, hornyhead chub, common shiner, bluntnose minnow, creek chub, white sucker, fantail darter, and johnny darter—were present at over half the stations within each of the three clusters. Stations in Cluster One usually had many species of cyprinids (stonerollers, chubs, shiners, minnows, dace), catostomids (suckers, redhorse, quillback, buffalos), and darters, as well as stonecat and smallmouth bass. Stations in Clusters Two and Three tended to have fewer species; northern hog sucker, redhorse, and banded, blackside, and slenderhead darters were infrequently encountered at stations in both clusters. Additionally, rosyface, spotfin, and sand shiners, stonecat, and smallmouth bass were rarely encountered at stations in Cluster Three.

Clusters Four and Five differed from the other three clusters in that most species were present at less than half of their stations (Table 3). Cluster Five had no species present at more than 75% of its stations, while Cluster Four had only 2, common shiner and bluntnose minnow. When only species present at 25% or more stations within a cluster were considered, Cluster Four was most similar to Cluster One, but most species were over twice as likely to be found at Cluster One stations than at Cluster Four stations. The species composition of stations in Cluster Five was somewhat different from stations in other clusters. The species most likely to be encountered at Cluster Five stations were carp and catostomids; most cyprinids, darters, stonecat, and smallmouth bass were rarely encountered.

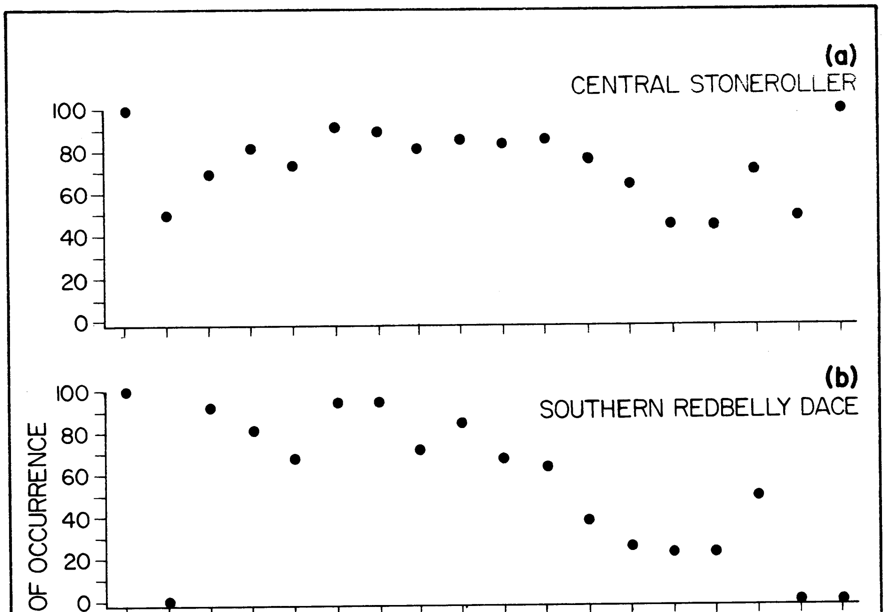


FIGURE 3. *Representative plots from direct gradient analysis showing (a) no obvious relationship between a species' frequency of occurrence and the environmental variable, in this case* log_{10} *average width, (b) a negative relationship, (c) a positive relationship, and (d) a relationship with a peak at intermediate values of the environmental parameter.*

Thus, cluster analysis indicates that there are few distinct well-defined species assemblages. Most clusters either lack a characteristic assemblage (Four, Five) or else have a characteristic assemblage similar to that of other clusters (One, Two, Three).

Two species, rosyface shiner and stonecat, had the same pattern of frequency of occurrence among clusters as smallmouth bass (Table 3). These 3 species were found at most stations in Clusters One and Two, but relatively few stations in Clusters Three, Four, and Five. For the remainder of the paper these 3 species will be referred to as the "smallmouth bass assemblage." Suckermouth minnows and sand shiners had a pattern of occurrence frequencies among clusters similar to that of the smallmouth bass assemblage. Central stonerollers, hornyhead chubs, common shiners, bluntnose minnows, creek chubs, white suckers, fantail darters, and johnny darters were usually encountered together with the smallmouth bass assemblage, but they were also often found where the smallmouth bass assemblage was absent.

Stepwise discriminant analysis (SDA) identified those species important in distinguishing clusters. Thirty-one of the 39 species used in analyses contributed to the discriminant function, and together the 31 accounted for 69% of the variance among clusters. The 10 most important species (together explaining 55% of the variance), in order of their *F* statistics, were: silver redhorse, stonecat, central stoneroller, banded darter, suckermouth minnow, smallmouth bass, rock bass, southern redbelly dace, bluegill*, and creek chub. Rosyface shiners were twelfth in importance. Thus, the presence or absence of all three members of the smallmouth bass assemblage was important in defining clusters. Species

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*Bluegills were found at less than 20% of the stations within each cluster, and therefore are not included in Table 3.

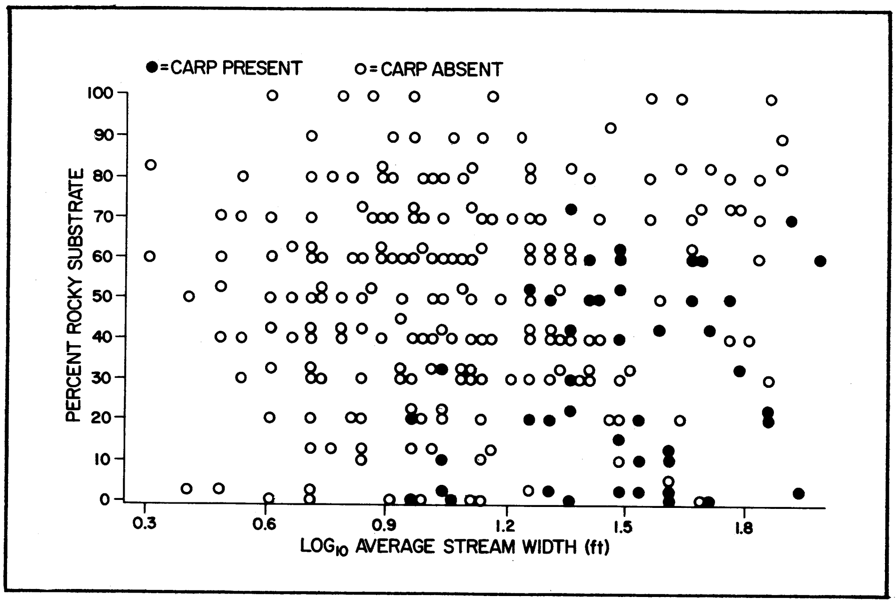

FIGURE 4. *Example of bivariate plot from direct gradient analysis, showing distribution of common carp among stations relative to the $\log_{10}$ average width and percent rocky substrate at each station. (Because of space limitations, 87 observations could not be shown.)*

such as white sucker, which were fairly constant among clusters in their frequency of occurrence, played a lesser role in distinguishing clusters and thus did not contribute to the discriminant function.

Mean values for most environmental parameters differed among clusters (Table 4). Stations in Cluster Three were the most distinct; they were the narrowest, shallowest, coldest, least turbid, and had the highest percentage of agricultural land along their banks. Clusters One, Two, Four, and Five were similar to each other in width, depth, and velocity. Cluster One stations were the warmest and most turbid, while Cluster Two stations had the most rocky substrate. Cluster Four stations had the lowest agricultural land use along their banks, and along with stations in Cluster Five, the least rocky substrate.

Stepwise discriminant analysis quantitatively determined the environmental variables most important in distinguishing the five clusters. Seven of the nine environmental variables in Table 4 contributed to the discriminant function, but together these seven only accounted for 21% of the variance among clusters. In order of importance the variables were: minimum depth, maximum width, minimum width, turbidity, percent rocky substrate, percent agricultural land use, and temperature. Higher percent rocky substrate distinguished stations in Clusters One, Two, and Three from Clusters Four and Five, while the other six variables primarily distinguished stations in Clusters One, Two, Four, and Five from those in Cluster Three.

We also used SDA to identify the most important environmental variables that distinguished stations likely to have the smallmouth bass assemblage (stations in Clusters One and Two, combined) from stations not likely to have the smallmouth bass assemblage (stations in Clusters Three, Four, and Five, combined). Four variables contributed to the discriminant function and together accounted for 20% of the variance between the two groups of stations. In order of importance the variables were: maximum width, temperature, turbidity, and minimum width. These were variables which primarily distinguished stations in Cluster Four from stations in other clusters; most of the stations in the group of clusters that did not usually

TABLE 3. *Percentage frequency of occurrence at stations within each of the five clusters generated by cluster analysis. Only species present at at least 25% of the stations within a cluster are included in this table.*

	Cluster				
Species	1	2	3	4	5
Species present at 75% or more of stations within at least one cluster					
Central stoneroller	71	│100│*	│90│	30	0
Hornyhead chub	│96│	│98│	55	20	3
Common shiner	│100│	│97│	│78│	│85│	30
Rosyface shiner	│93│	68	5	35	23
Spotfin shiner	│82│	21	6	60	27
Suckermouth minnow	50	│79│	7	0	7
S. redbelly dace	32	67	│88│	10	3
Bluntnose minnow	│93│	│95│	│75│	│75│	20
Creek chub	│75│	│86│	│96│	70	17
White sucker	│100│	│95│	│84│	70	60
N. hog sucker	│93│	8	4	5	13
Silver redhorse	│75│	0	0	5	50
Golden redhorse	│96│	21	2	10	23
Shorthead redhorse	│96│	33	1	10	67
Stonecat	│89│	73	4	15	10
Smallmouth bass	│93│	68	6	20	13
Fantail darter	│86│	│92│	73	25	0
Johnny darter	68	│92│	│84│	25	0
Banded darter	│86│	6	1	35	3
Species present at 25-74% of stations within at least one cluster					
Brown trout	7	17	20	│25│	23
Largescale stoneroller	│43│	2	5	0	0
Common carp	│57│	14	1	│40│	│57│
Bigmouth shiner	18	│65│	│43│	10	7
Sand shiner	│61│	│48│	1	│35│	20
Fathead minnow	18	17	│47│	20	3
Longnose dace	0	│48│	16	0	0
Quillback	│46│	8	1	5	│50│
Bigmouth buffalo	18	0	0	5	│47│
Black bullhead	7	21	6	│35│	0
Brook stickleback	0	11	│45│	10	7
Rock bass	│46│	0	0	10	0
Green sunfish	18	│27│	10	5	3
Blackside darter	│36│	0	1	10	0
Slenderhead darter	│50│	5	1	│25│	13
Walleye	7	0	0	0	│30│
Number of stations in cluster	28	66	185	20	30

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* Vertical bars highlight occurrences at 75% or more of the stations (first group) or 25% (second group).

TABLE 4. *Mean environmental parameters for stations within each of the five clusters generated by cluster analysis.*

Environmental Parameters	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Minimum width (ft)	24 *	18 (65)	6	22	26 (29)
Maximum width (ft)	33	37 (65)	13	31	36 (29)
Minimum depth (ft)	0.6	0.4	0.2	0.9	1.3(29)
Maximum depth (ft)	2.9	3.2(69)	2.3	3.2	3.7(29)
Velocity	2.0	2.0(64)	1.9	1.8	2.0(29)
Temperature (F)	70	64 (65)	61 (183)	64 (19)	62 (29)
Turbidity	3.5(26)	2.6(54)	2.0(168)	3.1(16)	3.1(28)
Agricultural land use (%)	46	61	77 (184)	34	36 (29)
Rocky substrate (%)	46	54	53	25	25 (29)
Number of stations in cluster	28	66	185	20	30

* Means for all stations within a cluster. If a parameter was not measured at all stations, the sample size is included in parentheses. For velocity and turbidity, qualitative scales were used (Fago 1984). *Velocity*: 0 = none, 1 = sluggish, 2 = moderate, 3 = rapid. *Turbidity*: 1 = clear, 2 = slightly turbid, 3 = moderately turbid, 4 = turbid.

have the smallmouth bass assemblage were in Cluster Four (185 of 325). We then excluded Cluster Four stations and reran the SDA in order to discriminate between stations that were similar in width. Three variables contributed to the discriminant function and together explained 33% of the variation between the two groups of stations. In order of importance the variables were: percent rocky substrate, minimum depth, and percent agricultural land use. After the influence of percent rocky substrate and minimum width were removed, percent agricultural land use accounted for less than 1% of the variation between groups of stations. Thus the smallmouth bass assemblage was most likely to be found at stations 20-35 ft wide, with substantial shallow and rocky areas.

A map designating the geographic location and cluster grouping of every station indicated that differences existed among clusters in geographic distribution (Fig. 5). All of the stations in Cluster One and most of those in Clusters Four and Five were found in the Pecatonica Basin (Basin 223; east), while most of the stations in Cluster Two were in the Grant/Platte-Galena Basin (Basin 230; west). Cluster Three stations were widely distributed in both basins, and were most numerous near basin boundaries. This, coupled with their small widths and depths, indicates that these stations were located on small tributaries and headwater streams. Stations downstream of Cluster Three stations were part of Clusters One, Two, Four, or Five. In the Grant/Platte-Galena Basin most of these downstream stations were part of Cluster Two and therefore usually contained the smallmouth bass assemblage. In the Pecatonica Basin some downstream areas were part of Cluster One and therefore also usually contained this assemblage, but many other downstream stations belonged to Cluster Four or Five and rarely contained the smallmouth bass assemblage.

PRINCIPAL COMPONENTS ANALYSIS (PCA)

Overall, a PCA with five PC's could explain only a moderate amount, 49%, of the variance in species distribution. Principal Component 1 (PC1) explained 20.4% of the variance and was negatively correlated with the presence/absence of most of the species that were negatively associated with stream width and depth in DGA, and positively correlated with the presence/absence of those positively associated with width and depth in DGA (Table 5). All members of the smallmouth bass assemblage had large positive correlations with PC1. In a stepwise multiple regression (SMR), PC1 was strongly positively correlated with log average stream width and only weakly correlated with other environmental variables (Table 6). In a univariate analysis, PC1 was also correlated with log maximum depth, but because average width and maximum depth were correlated with each other, maximum depth did not significantly contribute to the SMR. Based on PCA, the most important environmental variable influencing most species was stream size, as measured by average width and maximum depth.

After taking into account the effect of stream size, the next most important variable was rocky substrate. Principal Component 2 (PC2) explained 14.5% of the variance and was positively correlated with most species, including all of those in the smallmouth bass assemblage (Table 5). Species positively correlated with PC2 were also all positively associated with the percentage of rocky substrate in DGA; PC2 was weakly correlated with the percentage of rocky substrate in a SMR.

None of the other three PC's explained more than 7% of the variation and they will not be considered further.

A plot of PC1 vs. PC2 (Fig. 6) suggested that the species compositions of fish assemblages in southwestern Wisconsin overlapped substantially and changed gradually in relation to each other. Points (stations) in the plot were scattered along gradients, rather than isolated into separate groupings that would characterize distinct and separate fish assemblages. Stations spaced far apart in the plot had very different fish assemblages, but there were many intermediate stations that contained species from both extremes. Overall, most stations had negative scores for PC1 and low positive scores for PC2, but a wide variety of other combinations of scores was also present. These results are consistent with the results of cluster analysis, in which many species were frequently encountered at stations in two or more clusters.

DISCRIMINANT ANALYSES

A stepwise discriminant analysis (SDA) was performed on stations with and without smallmouth bass, using other species as variables. Seven of the 38 species used in the analysis contributed to the discriminant function and accounted for 49% of the variance between the two types of stations. In order of importance the species were: stonecat, sand shiner, hornyhead chub, golden redhorse, rosyface shiner, green sunfish, and common carp. Stonecats, sand shiners, green sunfish, and common carp were important in the function because they tended to occur most commonly at stations where smallmouth bass were present; hornyhead chubs, golden redhorse, and rosyface shiners were important because they usually were absent from stations that lacked smallmouth bass.

The discriminant function generated from the above analysis was used to classify stations into two classes, one with smallmouth bass and the other without. This classification was then compared with the observed presence/absence data for smallmouth bass (Table 7). The classification was significantly better than that based on chance alone (Kappa = 0.69, Z = 9.8, $P < 0.0001$), with a total of 88% of the stations classified correctly. The discriminant function corresponded well with actual data at stations where smallmouth bass were not found, because the function predicted that smallmouth bass should be present at only 5% of the stations where they were not actually captured. However, at 29% of the stations at which smallmouth bass were actually observed, the function predicted that bass should be absent. This suggests that the 7 species most important in the function (see previous paragraph) are generally more limited in their distribution, and indicates that the smallmouth bass occurs at some stations where most of these species are absent.

A second SDA was performed on stations with and without smallmouth bass, using environmental parameters as variables. Only two of the eight variables used, log average width and temperature, contributed to the discriminant function, and together the two accounted for 27% of the variance. Stations with smallmouth bass tended to be wider and warmer than those without smallmouth bass.

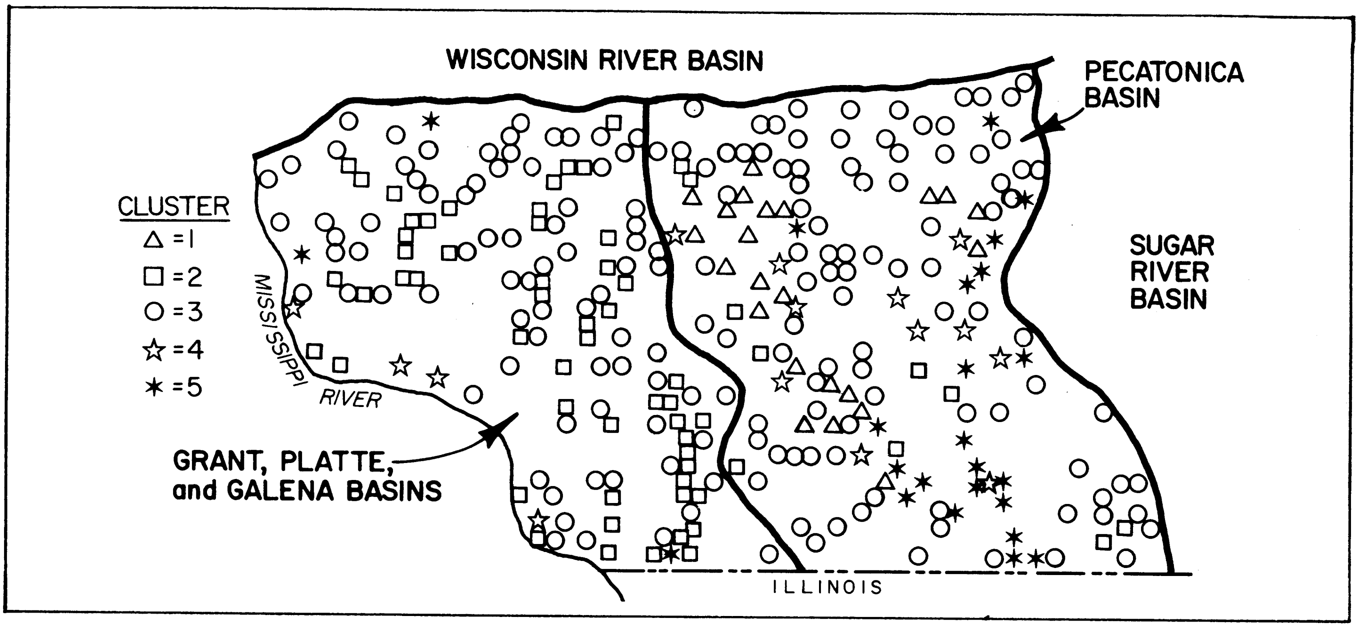


FIGURE 5. *Map of the geographic distribution of stations within the five clusters generated by cluster analysis. (Because of space limitations, 31 observations could not be shown.)*

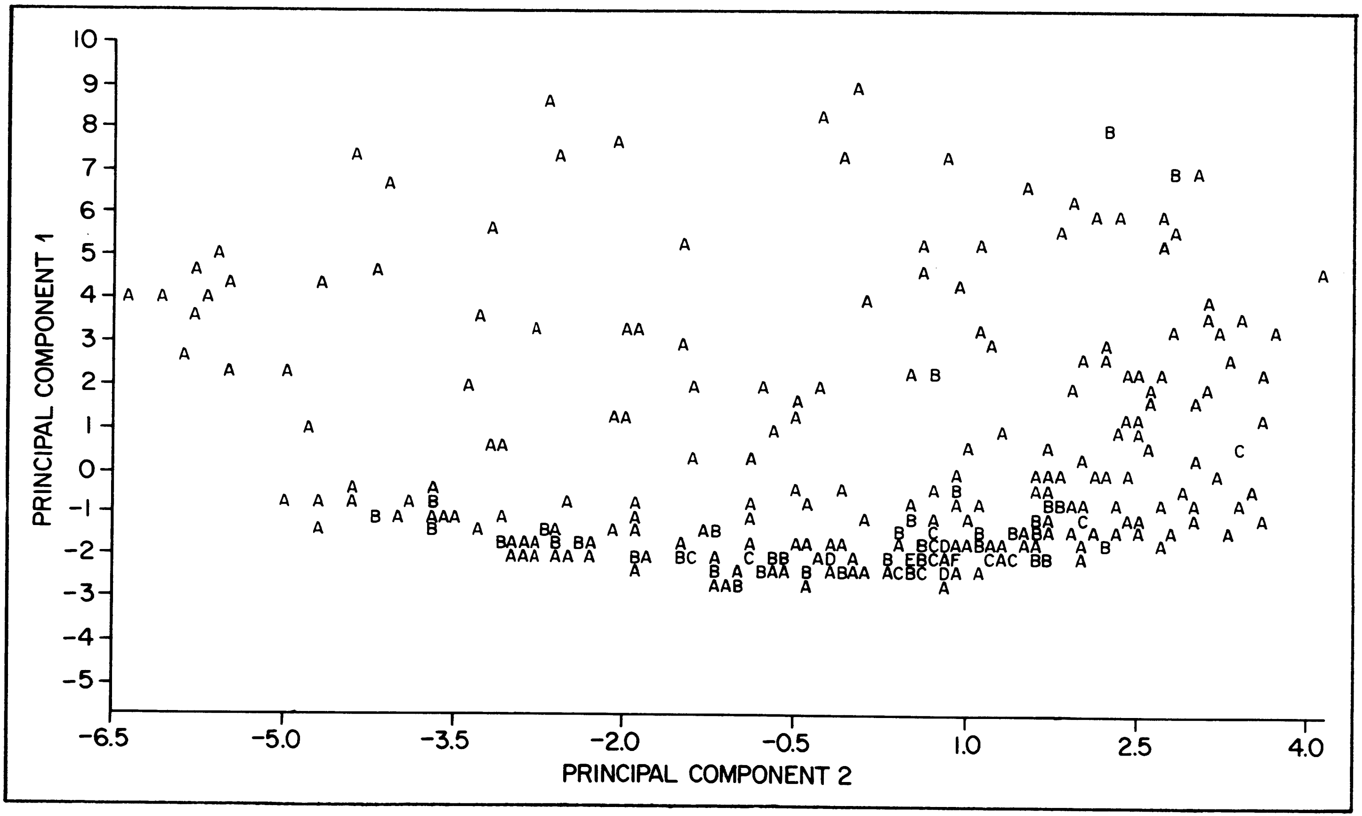


FIGURE 6. *Plot of first two principal components from principal components analysis. Each point represents a sampling station (A = 1 point, B = 2 points, C = 3 points, etc.).*

TABLE 5. *Species whose presence/absence was significantly correlated with the first two principal components (PC's) calculated by principal components analysis. Species with a correlation of greater than or equal to 0.5 (maximum possible = 1.0) are in boldface.*

PC1 (20.4%)*		PC2 (14.5%)	
Positive Loadings	Negative Loadings	Positive Loadings	Negative Loadings
Largescale stoneroller	Brown trout	**Central stoneroller**	Carp
Common carp	Central stoneroller	**Largescale stoneroller**	Quillback
Hornyhead chub	Bigmouth shiner	**Hornyhead chub**	Bigmouth buffalo
Rosyface shiner**	**S. redbelly dace**	**Common shiner**	Silver redhorse
Spotfin shiner	Fathead minnow	**Bigmouth shiner**	Mottled sculpin
Sand shiner	Blacknose dace	Ozark minnow	
Suckermouth minnow	Longnose dace	Rosyface shiner**	
Quillback	Creek chub	Sand shiner	
N. hog sucker	Brook stickleback	Suckermouth minnow	
Bigmouth buffalo	Johnny darter	S. redbelly dace	
Silver redhorse	Mottled sculpin	**Bluntnose minnow**	
Golden redhorse		Fathead minnow	
Shorthead redhorse		Longnose dace	
Stonecat**		Creek chub	
Smallmouth bass**		White sucker	
Banded darter		N. hog sucker	
Slenderhead darter		Golden redhorse	
		Black bullhead	
		Stonecat**	
		Green sunfish	
		Smallmouth bass**	
		Fantail darter	
		Johnny darter	
		Banded darter	

* Percent of variance explained by the PC.

** Member of smallmouth bass assemblage identified in cluster analysis.

TABLE 6. *Stepwise multiple regression of the first two PC's (PC1 and PC2) from a principal component analysis on environmental variables.**

PC1			PC2		
Variable	Association	Cumulative R^2	Variable	Association	Cumulative R^2
Log_{10} avg. width	+	47	Rocky substrate (%)	+	10
Turbidity	+	53	Sampling date	+	13
Temperature	+	57	Log_{10} max. depth	+	14
Rocky substrate (%)	−	59	Agricultural land use (%)	+	15
Velocity	+	60			

* Only environmental variables adding significantly to the regression are shown.

TABLE 7. *Observed numbers of stations with and without smallmouth bass, and predicted numbers based on discriminant analysis.*

		Predicted Number of Stations		
Observed Number of Stations		Without Smallmouth Bass	With Smallmouth Bass	Percent Misclassified Stations
Without smallmouth bass	239	226	13	5
With smallmouth bass	90	26	64	29
Total	329	252	77	12

DISCUSSION

Our broad geographical comparison of current and historical fish distribution data did not reveal major changes in smallmouth bass distribution, even though smallmouth bass fisheries are known to have declined in several southwestern Wisconsin streams (Forbes 1985 and in press; Kerr, unpubl. data). We probably failed to detect these declines because we examined presence/absence rather than absolute abundance; even in streams where the decline in bass abundance has been greatest, at least a few bass usually remain (Forbes 1985; Kerr, unpubl. data).

Few substantial changes in fish distribution appear to have occurred in southwestern Wisconsin streams during the last 50 years. Most species captured historically were found in approximately the same areas during the Fish Distribution Survey in the 1970s. All 16 species captured from the region for the first time in the survey were not widely distributed, and their appearance in recent samples was probably caused by more widespread and intensive sampling and the use of electroshockers, rather than by a true expansion in range. Historical collectors sampled fewer sites (Fago 1982, 1985) and used seines almost exclusively (Greene 1935, Becker 1966). In streams, seines typically catch a lower number and diversity of fish than electroshockers (Wiley and Tsai 1983). The 5 previously reported species that were absent from survey samples probably have actually disappeared from southwestern Wisconsin streams, but none were ever common in the region.

Only 2 common species, longnose dace and fantail darter, appear to have had substantial changes in distribution. Both of these species have increased in distribution, possibly in response to human modifications of streams and watersheds. Longnose dace and fantail darters are moderately tolerant of siltation and turbidity and are able to withstand rapid changes in temperature and flow (Becker 1983), all characteristics of streams in agricultural watersheds (Knox 1977, Schlosser and Karr 1981, Menzel et al. 1984, Barton et al. 1985). In southern Canada, longnose dace expanded their range up a river, presumably because of warming of the river caused by deforestation and agricultural development of the riparian zone (Mahon et al. 1979, Barton et al. 1985).

Distinct, well-defined fish species assemblages were not present in southwestern Wisconsin streams. Analyses suggested that instead there was a continuum of species associations from the smallest streams to the largest rivers considered. The fish assemblages in small streams were quite different from those in larger streams, but there was no definitive boundary between these assemblages. A few species were generally restricted to the largest or smallest waters, but most occurred over a wide range of stream sizes. This pattern is not surprising, since physical/chemical conditions change gradually within the region, and since there are few barriers to upstream or downstream movement. It is also consistent with the river continuum concept, in which the physical gradients from the headwaters to the mouth of a river system are believed to structure biotic communities into "continua consisting of mosaics of intergrading population aggregates" (Vannote et al. 1980).

The most important environmental characteristic influencing the number and kind of species at a station was stream size, as measured by width and depth. The presence/absence of most species was strongly associated with width and depth in DGA, and width or depth or both were identified as the most important environmental variables in all multivariate analyses. In most other studies on stream fish assemblages, stream size (width and depth) has also been found to be a major determinant of assemblage structure and overall species richness (Gorman and Karr 1978, and references therein).

The other environmental variables considered in this study—velocity, water temperature, turbidity, percent agricultural land use, and percent rocky substrate—appeared to have less influence on species distribution than stream size. Of these five variables, water temperature and percent rocky substrate were most important, but when the influence of stream size was taken into account both explained relatively little variance. Our analyses may have underestimated the importance of these five variables in determining species distributions in southwestern Wisconsin streams; for velocity and turbidity only a narrow range of values was encountered, and the imprecise nature of estimates for all environmental variables may have obscured all but the strongest relationships. In other parts of North America all of the environmental variables considered here have been found to influence the distribution of fish species, including smallmouth bass (e.g., Trautman 1942, Larimore and Smith 1963, Paragamian 1981, Edwards et al. 1982, Menzel et al. 1984, Mathur et al. 1985, Matthews 1985, Rankin 1986).

Multivariate analyses individually explained less than half of the variance in species distributions, but when considered together consistently identified several general, if somewhat loosely defined, assemblages of fishes. Three small fish species (maximum total length less than 4 inches), southern redbelly dace, fathead minnow, and brook stickleback, characterize the headwaters assemblage (Fig. 7). Members of this assemblage are often encountered in small headwaters and tributary streams, but are infrequently encountered in larger streams. All species in the assemblage are tolerant of the extreme and variable conditions that are typical of many small streams (Smith and Powell 1971, Whiteside and McNatt 1972, Williams and Coad 1979, Matthews and Styron 1981), although southern redbelly dace and brook sticklebacks may be relatively intolerant of some of the environmental changes resulting from intensive agricultural land use in the riparian zone (Menzel et al. 1984). All 3 species may be less commonly encountered in downstream areas because of competition from or predation by other species (Matthews 1985; see also Tonn and Magnuson 1982 and Rahel 1984, for a discussion of how competition and predation influence the distribution of some headwaters species in lakes).

Another obvious species assemblage is the large-stream assemblage, characterized by common carp and several catostomids (Fig. 8). Members of this assemblage are commonly found in the largest streams, but are rare in headwaters and small tributaries. Species in this group reach a larger maximum size (maximum total length greater than 12 inches) than headwaters species. Most members of the large-stream assemblage are probably excluded from headwaters areas because they are relatively intolerant of environmental extremes and sudden variability (Paloumpis 1958, Kushlan 1976, Gorman and Karr 1978, Horowitz 1978, Karr 1981), but the lack of necessary habitats and foods may also contribute to their absence (Sheldon 1968, Gorman and Karr 1978, Horowitz 1978, Schlosser 1982, Felley and Hill 1983, Matthews 1985).

Rosyface shiners, stonecats, and smallmouth bass constitute the smallmouth bass assemblage (Fig. 9). The distribution of this assemblage overlaps substantially with that of the large-stream assemblage. The smallmouth bass assemblage is more frequently encountered at stations with extensive rocky shallows, while the large-stream assemblage is more frequently encountered in areas with few rocky shallows. Like the large-stream assemblage, the smallmouth bass assemblage is rarely found in small tributaries, probably because of an intolerance of environmental extremes and sudden variability, coupled with an absence of suitable habitat and foods (Edwards et al. 1982, Schlosser 1982).

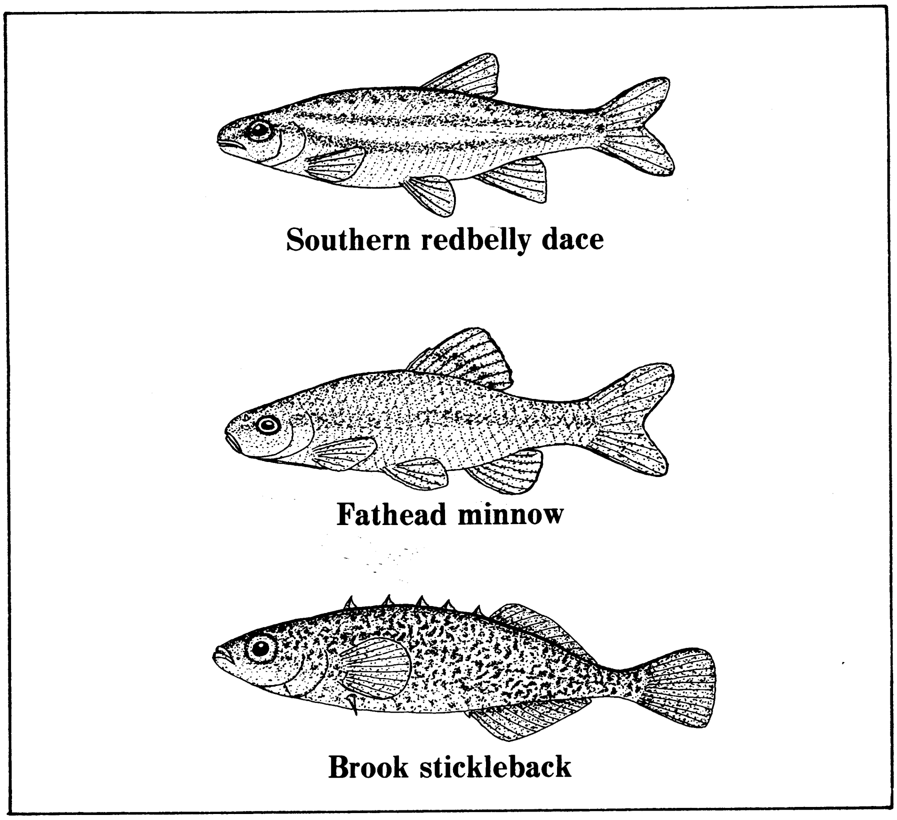


FIGURE 7. *The three characteristic members of the headwaters assemblage.*

Finally, there is an assemblage of widely distributed fishes characterized by central stoneroller, hornyhead chub, common shiner, bluntnose minnow, creek chub, white sucker, and fantail and johnny darters (Fig. 10). These fishes are absent only from the largest or smallest stations and presumably are tolerant of both the extremes and variability in environmental conditions of headwaters, and of the more intense or complex species interactions of larger streams (Sheldon 1968, Gorman and Karr 1978). Some species, such as common shiner and white sucker, are habitat generalists, while others, such as central stoneroller, appear to be habitat specialists whose habitat, in this case shallow pool margins near riffles, is present in all sizes of streams (Felley and Hill 1983, Matthews 1985).

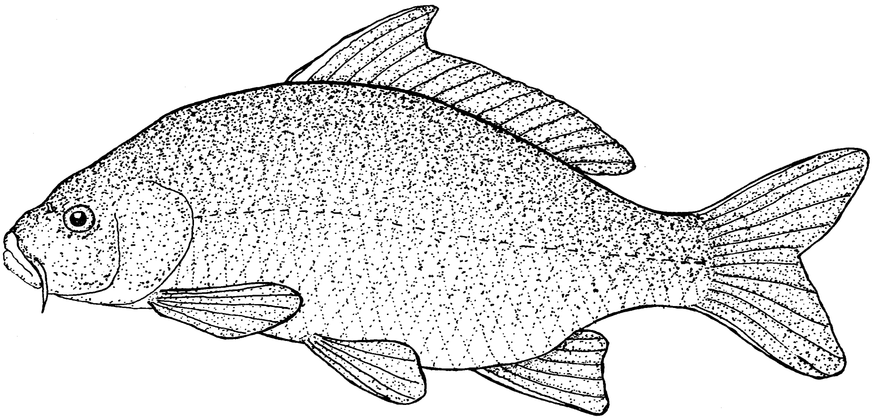
Attempts to identify and quantitatively define fish assemblages in warm water streams have been made in a number of geographic regions, but most work has concentrated in the south central United States (Rose and Echelle 1981, and references therein). No previous work has been done in Wisconsin, and, excepting Menzel et al. (1984), only qualitative assessments of warm water streams have been made in states bordering Wisconsin (Shelford 1911, Starrett 1950, Larimore and Smith 1963, Smith 1971).

Menzel et al. (1984) used univariate and multivariate analyses to quantify the habitat characteristics and structure of fish assemblages in 10 streams in an area of high agricultural land use in east central Iowa. These streams were similar in width and depth to the smallest streams in southwestern Wisconsin and tended to be dominated by many of the same species that were frequently encountered in small streams in southwestern Wisconsin, including central stoneroller, common shiner, bluntnose minnow, fathead minnow, creek chub, white sucker, and johnny darter. The Iowa streams contained 22 other species, 21 of which were widely distributed in southwestern Wisconsin streams. Menzel et al. (1984) attributed the scarcity of hornyhead chub, rosyface shiner, southern redbelly dace, northern hog sucker, brook stickleback, smallmouth bass, and fantail darter in the Iowa streams to high levels of turbidity and siltation that resulted from intensive agriculture in the watersheds of the streams. Our analyses on southwestern Wisconsin streams suggest that the small size of the Iowa streams may have also contributed to the limited distribution and low abundance of hornyhead chub, rosyface shiner, northern hog sucker, and smallmouth bass.

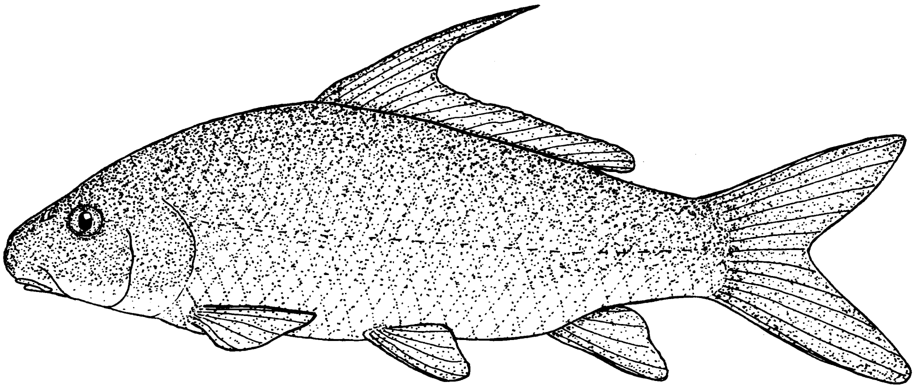
Aside from those studied by Menzel et al. (1984), streams for which multivariate analyses of fish assemblage structure exist have few species in common with streams of southwestern Wisconsin. However, some of the patterns in fish distribution observed in these other streams are similar to those observed in southwestern Wisconsin streams. Nearly all other studies have found headwaters assemblages and large-stream or river assemblages, even though the characteristics of watersheds differ substantially among studies (Smith and Fisher 1970, Smith and Powell 1971, Stevenson et al. 1974, Rose and Echelle 1981, Felley and Hill 1983, Grady et al. 1983, Ross et al. 1985). Only in the Kiamichi River, Oklahoma, was a clear headwaters assemblage absent (Echelle and Schnell 1976). As in southwestern Wisconsin, some studies have also found a group of species that were present over most or all of the range of stream sizes sampled (e.g., Felley and Hill 1983).

Where there are species or taxa in common between other streams and those of southwestern Wisconsin, they often belong to the same assemblage. For example, redbelly dace and brook sticklebacks are part of headwater assemblages in nearly all drainages studied elsewhere (Shelford 1911, Burton and Odum 1945, Starrett 1950, Hallam 1959, Stevenson et al. 1974, Williams and Coad 1979, Felley and Hill 1983). Central stonerollers, creek chubs, white suckers, and johnny darters, present in small to large streams in Wisconsin, had a similar distribution in other drainages (Starrett 1950, Kuehne 1962, Larimore and Smith 1963, Sheldon 1968, Lotrich 1973, Echelle and Schnell 1976, Mundy and Boschung 1981, Felley and Hill 1983). In all other studies, as in southwestern Wisconsin, common carp and catostomids were part of a large-stream or river assemblage, while smallmouth bass were mainly found in medium to large streams or rivers (Shelford 1911, Burton and Odum 1945, Starrett 1950, Hallam 1959, Kuehne 1962, Larimore and Smith 1963, Sheldon 1968, Whiteside and McNatt 1972, Echelle and Schnell 1976, Rose and Echelle 1981).

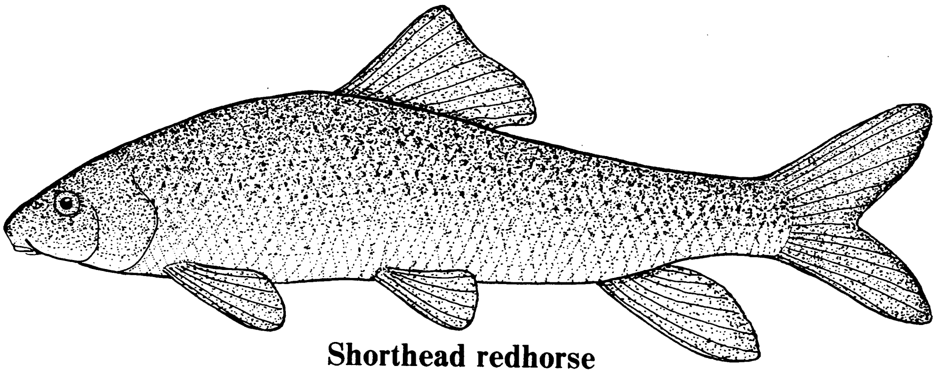
Not surprisingly, in other parts of the country a few species were associ-



Common carp



Quillback



Shorthead redhorse

FIGURE 8. *Three of the characteristic members of the large-stream assemblage.*

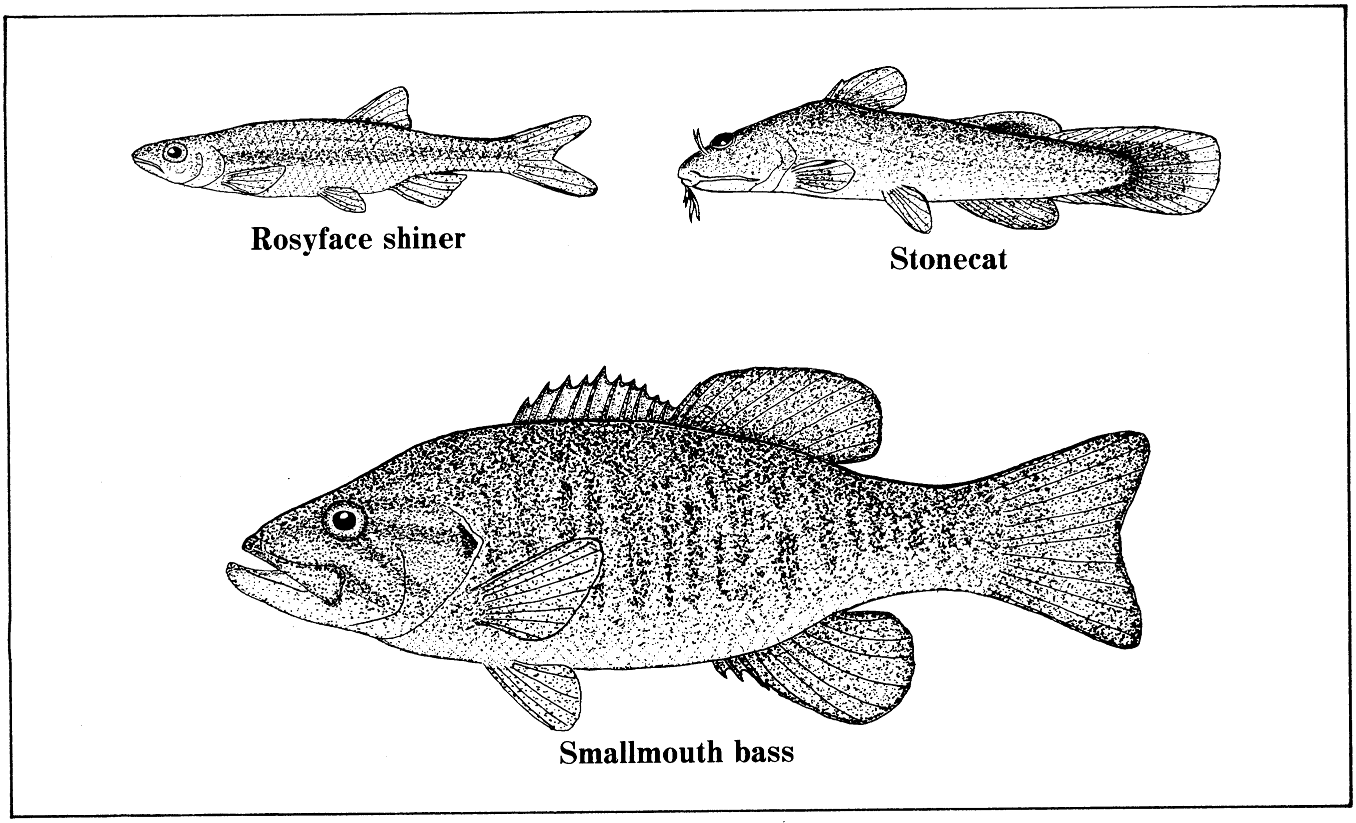


FIGURE 9. *The three characteristic members of the smallmouth bass assemblage.*

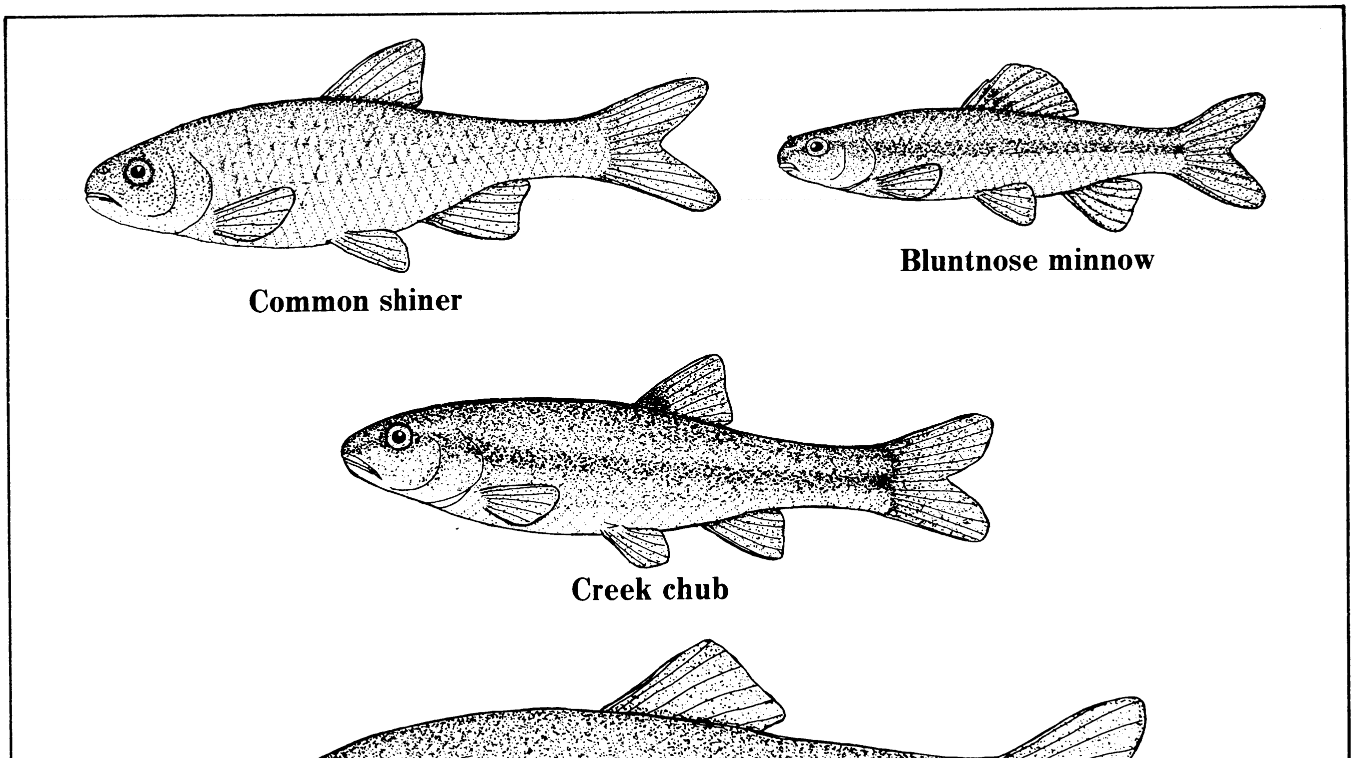


FIGURE 10. *Four of the species that are widely distributed in southwestern Wisconsin streams.*

ated with different assemblages than they were in southwestern Wisconsin. For example, fathead minnows, part of the headwaters assemblage in southwestern Wisconsin and several other areas (Starrett 1950, Paloumpis 1958, Smith and Powell 1971, Williams and Coad 1979), were common in large streams or rivers and often absent from the headwaters in some areas (Shelford 1911, Larimore and Smith 1963, Harrel et al. 1967, Sheldon 1968, Rose and Echelle 1981). There was no obvious geographic component to the habitat of fathead minnows. Areas where it was a headwater species were near drainages in which it was a large-river form. In one Oklahoma drainage where fathead minnows were part of the large-river assemblage, sunfishes and crappies were the dominant species in small streams (Rose and Echelle 1981). In southwestern Wisconsin streams, crappies and sunfishes, other than green sunfish, were uncommon (Table 1), but were most frequently encountered in larger streams.

Rosyface shiners and stonecats, which were closely associated with smallmouth bass in southwestern Wisconsin streams, were also commonly encountered with smallmouth bass in other regions. In streams in northeastern and central Illinois, both species were frequently captured with smallmouth bass; hornyhead chubs, golden and shorthead redhorse, northern hog suckers, and banded darters were also often found with the smallmouth bass (Shelford 1911, Larimore and Smith 1963). In the Susquehanna Basin of Pennsylvania, cluster analysis identified rosyface shiners as close smallmouth bass associates; stonecats were not present in this basin (Strauss 1982). In Ohio, "the stonecat was an excellent index of smallmouth blackbass abundance, for almost invariably, one was abundant only where the other was abundant" (Trautman 1981). However, in Missouri (Pflieger 1971) and southern Ontario (Hallam 1959, Mahon et al. 1979, Barton et al. 1985), stonecats and smallmouth bass were rarely encountered together, even though they were often both found in the same drainages. In Pennsylvania, Missouri, and southern Ontario, rock bass, along with rosyface shiners, were the best indicators of smallmouth bass presence/absence. When present in southwestern Wisconsin streams, rock bass were likely to be captured together with smallmouth bass, but rock bass were encountered at only 19 of 380 stations (Fago 1982, 1985). They are generally considered uncommon in this part of Wisconsin (Greene 1935, Becker 1983), so they are not a good indicator of smallmouth bass presence/absence.

MANAGEMENT IMPLICATIONS

STREAM SIZE AND SUBSTRATE COMPOSITION: IMPLICATIONS FOR WATERSHED MANAGEMENT

It appears that the most important environmental determinant of smallmouth bass distribution in southwestern Wisconsin is stream size. Smallmouth bass are unlikely to do well in streams less than 20 ft wide and will probably do best in streams greater than 25 ft wide. Stream depth is also important. Smallmouth bass do best in areas with a wide range of depths (i.e., both extensive shallows and deep holes).

Smallmouth bass are most likely to be encountered in large streams that have extensive amounts of rocky substrate and late spring water temperatures greater than 60 F. Many large streams in the Pecatonica Basin are over 60 F in May and June but have only limited rocky substrate and lack smallmouth bass. Loss of rocky substrate because of siltation is a common effect of intensive agricultural land use in a watershed (Menzel et al. 1984). Whether the scarcity of smallmouth bass in many parts of the Pecatonica Basin is a natural condition or due to recent siltation caused by agricultural land use is unknown. Nonetheless, efforts should be made to reduce siltation in order to prevent future declines in smallmouth bass habitat.

Although loss of rocky substrate through siltation is potentially a threat to smallmouth bass populations in southwestern Wisconsin, and siltation is often caused by cultivation or grazing in riparian areas, smallmouth bass distribution was not related to the amount of agricultural land use adjacent to sampling stations. In fact, percent rocky substrate was positively related to percent adjacent agricultural land use ($r = 0.21$, $P < 0.001$). This implies that loss of rocky substrate through siltation may not be caused solely by erosion of adjacent lands, but also by upstream erosion (see also Platts and Nelson 1985*a*). Thus, efforts to protect bass habitat through reductions in siltation must include upstream areas, headwaters, and small tributaries (which also have the highest amount of adjacent agricultural land use), even though these land use areas are unlikely to ever have substantial smallmouth bass habitat or populations.

How can erosion from upstream areas of watersheds be reduced? One solution is the continuation and expansion of the DNR Bureau of Water Resource Management's Priority Watershed Program. This program works to reduce nonpoint source pollution, including agricultural runoff and soil erosion, through integrated land management within entire watersheds (Konrad et al. 1985). Two watersheds in southwestern Wisconsin, the Upper West Branch of the Pecatonica River and the Galena River, are part of the program, and a third, the Lower East Branch of the Pecatonica River, is proposed for inclusion in 1987.

On a smaller scale, management of riparian zones may also help reduce siltation. Because easement and land acquisitions are underway or proposed for southwestern Wisconsin smallmouth bass streams (Kerr, Wis. Dep. Nat. Resour., pers. comm.), an obvious management recommendation is to consider the potential for managing riparian vegetation and land use in headwaters and small tributaries when selecting lands for purchase or easements. Ideally, efforts should be made to protect or establish buffer strips, in which there would be no cultivation or grazing, on each side of these small streams. While our study did not address the design and placement of these strips, other research indicates that the wider and longer they are, the more effective they will be (Barton et al. 1985). Realistically, however, the establishment of many miles of buffer strips on properties with many different landowners may be difficult, and on some streams the cost of fencing to exclude livestock from riparian areas may exceed the potential value of improved smallmouth bass fishing (Platts and Wagstaff 1984). In such cases, a modification of the buffer strip approach might be more practical, such as allowing only certain types of agriculture to be practiced in the riparian zone, or allowing cultivation and grazing to occur in some years but not in others (e.g., the rest-rotation grazing of Platts and Nelson 1985*b*).

Where should efforts to manage watersheds and riparian lands be concentrated? Our analyses were not designed to identify specific streams or locations, but they did identify some important variables to consider in choosing sites. Clearly watersheds with current or historical smallmouth bass fisheries should receive high priority. Watersheds that lack smallmouth bass but contain several other members of the smallmouth bass assemblage (see below) are also good candidates.

RELATIONSHIPS BETWEEN INSTREAM, RIPARIAN, AND WATERSHED MANAGEMENT

Is control of siltation the only environmental problem that needs to be addressed when managing smallmouth bass populations in southwestern Wisconsin streams? Clearly it is not. This paper only reports on the presence/absence of smallmouth bass and associated species over a broad geographic area, not the status of individual smallmouth bass populations. In another analysis we applied the U.S. Fish and Wildlife Service Habitat Suitability Index model for smallmouth bass (Edwards et al. 1982) to three southwestern Wisconsin streams that contained smallmouth bass (Append.). This model indicated that in at least 1 stream (Rattlesnake Creek, Grant County) siltation was not a problem, but smallmouth bass numbers were held below potential levels by factors unrelated to instream habitat. Instead, smallmouth bass numbers were low probably because of acute or sublethal water quality impacts other than siltation from agricultural land use in the watershed (Mason et al., in press). Efforts directed solely at maintaining or increasing rocky substrate would not improve the smallmouth bass population in this stream. However, coordinated efforts to manage riparian land use at the sampling station and along the stream's headwaters and tributaries, as well as in the watershed as a whole, might both alleviate water quality problems and prevent future siltation problems. It is our opinion that in order for declines in smallmouth bass populations in southwestern Wisconsin streams to be reversed, an integrated program of widespread riparian and watershed land use management must be undertaken.

SMALLMOUTH BASS AND THEIR ASSOCIATES: INDICATOR SPECIES FOR MANAGEMENT ACTIVITIES

Another implication for management of smallmouth bass in southwestern Wisconsin streams that resulted from our analyses relates to the species typically encountered with smallmouth bass. In southwestern Wisconsin, the presence of rosyface shiners and stonecats indicates habitats where smallmouth bass should be present. The presence of hornyhead chubs, sand shiners, and golden redhorse may also help indicate suitable smallmouth bass habitat; these species were important identifiers of smallmouth bass presence/absence in all three types of multivariate analyses. If most of these species are present, but smallmouth bass are absent, it may indicate an area where declines in habitat or water quality have selectively eliminated smallmouth bass. This may have been the case in the lower portion of Rattlesnake Creek; hornyhead chubs, rosyface shiners, golden redhorse, and stonecats were present but smallmouth bass were absent, although smallmouth bass were present farther upstream (Fago 1985). If environmental quality can be improved in such an area, it may be possible to successfully reestablish smallmouth bass there. Conversely, if smallmouth bass are present, but other species that are also relatively intolerant of environmental degradation, such as hornyhead chubs and rosyface shiners, are absent, it may indicate an area where the smallmouth bass population is threatened or stressed.

Rosyface shiners and stonecats may not be good indicators of smallmouth bass presence/absence in other regions of Wisconsin (Becker 1983; Lyons, unpubl. data). Further analyses will be necessary to identify smallmouth bass associates outside of southwestern Wisconsin, although rock bass appears to be a good candidate.

COMMUNITY LEVEL APPROACHES TO FISH MANAGEMENT: A RECOMMENDATION AND A CAUTION

The use of a community level approach that incorporates multivariate statistical techniques has broad implications for fish management in addition to those implications specific to southwestern Wisconsin smallmouth bass streams. Multivariate analyses are useful for identifying environmental variables that are important in determining the distribution of species or groups of species, particularly when there are numerous potentially important environmental variables that are likely to be correlated with each other. As an example, in this study multivariate analyses showed that stream size, water temperature, and amount of rocky substrate were important in determining the distribution of the smallmouth bass and its associates. With only univariate or bivariate analyses it was unclear if all were important, if other variables were also important, or if the correlation between fish distribution and any of the variables was spurious.

A community level analysis also identifies assemblages of organisms that tend to occur with each other, but not with other species. Often these assemblages are not obvious from distribution maps or ecological data. For instance, a group of species may have overlapping ranges and similar ecological requirements, but rarely occur together because of complex competitive or predatory interactions (e.g., Biehl and Matthews 1984). This sort of assemblage structure was not observed in southwestern Wisconsin streams, but may be important in small northern Wisconsin and Canadian lakes (Johnson et al. 1977, Tonn and Magnuson 1982, Rahel 1984). An analysis that identified this sort of assemblage structure could be used to establish management and stocking policy in an area (Mundy and Boschung 1981, Tonn et al. 1983). Also, as in this study, identification of assemblages may reveal potential indicator species whose absence from an area warns of potential problems for the species of management interest, or conversely, whose presence identifies an area where the species of management interest might be successfully introduced.

Another useful result of community level analyses using multivariate techniques is data reduction. Multivariate analyses condense large matrices of information into a few equations or values, such as a discriminant function or the loadings for a few principal components. Such equations or values can then be used as indices of environmental health or condition (e.g., Bloom 1980), or in the classification of stations for consideration of different management strategies (e.g., Tonn et al. 1983). Both approaches have potential for regionwide watershed or fish management programs. For instance, multivariate scores could be used to quantify changes over time in the overall condition of fish communities and associated fisheries that resulted from changes in environmental conditions brought about by physical habitat or water quality improvements (e.g., Karr 1981). In another application, multivariate analyses might allow managers to develop procedures for determining the fisheries potential of a location based on a few easily measured parameters. For example, based on results from this study, it might be possible to accurately predict the potential of streams in southwestern Wisconsin to support smallmouth bass by using only topographic (stream size) and soil (rocky substrate) maps, and measuring May and June water temperatures.

While we urge increased use of community level analyses that are based on multivariate statistical techniques, we also want to stress that these analyses are not a panacea for the problems facing fish managers in Wisconsin. As with other types of analyses, results of community level analyses are only as good as the data used as input. Imprecise data will lead to imprecise conclusions. In addition, large data sets are required for most multivariate techniques to be valid. The number of stations or samples should be at least two times greater than the number of parameters (species plus environmental variables) (Johnson and Wichern 1982, Gauch 1982).

We were certainly fortunate to have access to a large data set covering many locations in southwestern Wisconsin that included identification of all species and estimates of several environmental variables (Fago 1982, 1985). However, because environmental data were not collected to specifically quantify the relationships between fish distribution and environmental characteristics, the data were imprecise. As a consequence, despite our sophisticated statistical analyses, we were only able to describe these relationships in a fairly general, qualitative way. More detailed and precise land use and habitat data probably would have allowed development of more precise and quantitative relationships and perhaps more specific management recommendations. Thus, we strongly advocate continued development and use of community level analyses, but we also strongly urge that data collection be designed with specific program goals and analytical approaches in mind.

SUMMARY

1. We performed direct gradient analysis, cluster analysis, principal components analysis, and discriminant analyses on fish species presence/absence and environmental data collected from 1976-79 from 380 stations on 201 streams in southwestern Wisconsin.
2. There has been little historical change in the distribution of fish species in the region, although longnose dace and fantail darters have extended their ranges. Smallmouth bass have not decreased in distribution, even though the bass fishery on several streams has declined.
3. In direct gradient analysis, the distribution of most of the common species in the region was related to one or more of the following environmental variables: average stream width, maximum stream depth, percent rocky substrate, amount of agricultural land use adjacent to the station, and stream temperature.
4. Cluster analysis indicated that stations could not be organized into discrete, easily distinguished groups based on their fish fauna, although smallmouth bass tended to be most closely associated with stonecats and rosyface shiners.
5. Principal components analysis indicated that the most important environmental variable influencing fish species distribution was stream size, as measured by width and depth. Percent rocky substrate and stream temperature were also important.
6. Discriminant analysis also indicated that stonecat and rosyface shiner, as well as 5 other species, were usually associated with smallmouth bass.
7. Distinct, well-defined fish species assemblages were not found in southwestern Wisconsin streams. Rather, there was a continuum of gradually changing species associations going from the smallest to the largest streams sampled.
8. Although distinct fish species assemblages were absent, most fish species could be assigned to one of four loosely defined groups. The headwaters group was primarily found in small streams and was dominated by southern redbelly dace, fathead minnow, and brook stickleback. The large-stream group was primarily found in the largest streams sampled and was dominated by carp and members of the sucker family. The widely distributed group was found in nearly all types of habitat and consisted of central stoneroller, hornyhead chub, common shiner, bluntnose minnow, creek chub, white sucker, and fantail and johnny darters. The smallmouth bass group consisted of smallmouth bass, stonecat, and rosyface shiner. These 3 fishes were most often encountered in streams greater than 20 ft in average width, with both rocky shallows and deep holes, and May and June water temperatures greater than 60 F.
9. Siltation may have a negative impact on smallmouth bass populations in some southwestern Wisconsin streams. Riparian land management alone will probably not reduce this situation; rather, an integrated program of land management for entire watersheds is needed.
10. In some other streams, poor instream habitat is not the cause of bass population declines. Rather, water quality problems other than siltation appear to be the culprit. However, once again, an integrated program of land management for entire watersheds is probably the best way to improve bass fisheries in these streams.
11. In southwestern Wisconsin, the presence or absence of stonecat, rosyface shiner, and to a lesser extent, hornyhead chub, sand shiner, and golden redhorse is a good indicator of the potential of an area to support smallmouth bass.
12. Multivariate community analysis is a valuable approach to complex fisheries issues, with several advantages over more traditional univariate analyses. However, it is not a panacea and should only be applied in appropriate situations when appropriate data are available.

APPENDIX

HABITAT SUITABILITY INDEX FOR SOUTHWESTERN WISCONSIN SMALLMOUTH BASS STREAMS*

During the meeting which reviewed the *Final Report and Recommendations of the Working Group on Research Needs of Streams in Agricultural Watersheds*(27 September 1985, DNR Southern District Headquarters) there was much discussion about potential methods to reverse the decline of smallmouth bass populations in southwestern Wisconsin streams.

One method, which received verbal support from representatives of Southern District and the Bureau of Fish Management, was to initiate physical habitat improvement work on smallmouth bass streams in the region. Proposed work included deepening pools, removing silt from spawning gravel, stabilizing banks, and increasing instream and bankside cover.

In response to your query concerning the use of the Habitat Suitability Index (HSI), we present data using that model that suggest that these activities would not result in the restoration of bass fisheries and that it would be unwise to devote substantial resources to instream physical habitat improvement at this time. Rather, improved riparian and watershed management practices should receive immediate attention.

We examined the relationship between smallmouth bass abundance and habitat quality in three southwestern Wisconsin streams, Rattlesnake Creek (Grant County), which once had a good bass population but now does not support a fishery; the Galena River (Lafayette County); and Pat's Creek (Lafayette County), a tributary of the Galena. The Galena River and Pat's Creek have two of the better bass populations remaining in this part of the state (Forbes 1985).

We quantified habitat quality using the U.S. Fish and Wildlife Service's HSI model for smallmouth bass (Edwards et al. 1982). This HSI model incorporates 13 physical and chemical variables, including dominant substrate type in pools, average maximum depth of pools, and amounts of instream and bankside cover, into an overall index that rates the suitability of a stream for smallmouth bass. An index value of 1.00 indicates optimum habitat, while a value of 0.00 indicates that a bass population could not persist.

Based on the HSI model, all three streams had good to excellent habitat (Append. Table A.1). The Galena River, which had a large number of quality-sized bass, and Rattlesnake Creek, which had a low number, both had habitats close to optimum. The two stretches of Pat's Creek, both of which had large numbers of bass, had somewhat lower HSI values, but overall habitat quality was still relatively good. Only in the upper stretch of Pat's Creek (below Highway 81) did it appear that physical habitat improvement work might be beneficial. This stretch is narrow, heavily grazed by cattle, and used rarely, if ever, by anglers at the present time. Creation of a "showcase" fishery here, through physical habitat improvement, might attract large numbers of anglers. In this case, restrictive regulations such as catch-and-release would be essential. In addition, this fishery would be extremely vulnerable to fish kills from runoff-related climatic events.

The only habitat variable that was substantially below optimum in all three streams was average maximum depths of pools. However, even if each stream was dredged until the average maximum pool depth was at an optimum value, the overall HSI estimate of habitat quality would only increase 0.02 or 0.03. Whether or not this would increase the carrying capacity for bass is unknown.

We feel that efforts to rehabilitate

APPENDIX TABLE A.1. *Habitat quality and relative smallmouth bass density in three southwestern Wisconsin streams.*

		Habitat Scores <0.7**		Electrofishing
Location	HSI* Score	Variable	Score	Catch/ha[a]
Rattlesnake Creek, near Highway 81 (Grant County)	0.94	Avg. max. depth of pools	0.45	4 (1984-85)
Galena River, near Highway 11 (Lafayette County)	0.96	Avg. max. depth of pools	0.60	41 (1981-83)
Pat's Creek, below Highway 81 (Lafayette County)	0.63	Avg. max. depth of pools	0.45	49 (1981-84)
		Dominant substrate in pools	0.20	
		% cover in pools	0.25	
Pat's Creek, above Back Road (Lafayette County)	0.78	Avg. max. depth of pools	0.50	60 (1981-84)
		Dominant substrate in pools	0.50	
		% cover in pools	0.50	

* Habitat Suitability Index for smallmouth bass. Maximum value (optimum habitat) = 1.00.

** Each of 13 variables is rated from 0.00-1.00 (with 1.00 being optimum), and then combined to calculate the overall HSI score.

[a] Average of summer electrofishing catch/ha during the years given in parentheses for bass greater than or equal to 200 mm total length.

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* Memo of 19 November 1985 to Ron Poff, DNR Bureau of Fish Management, describing application of the U.S. Fish and Wildlife Service's Habitat Suitability Index Model for smallmouth bass at four locations on three southwestern Wisconsin streams. Details on how habitat data were collected are given in Forbes (in press).

smallmouth bass populations in southwestern Wisconsin should be directed primarily toward improvements in watershed management practices rather than instream habitat modifications. Rattlesnake Creek has excellent bass habitat, but few bass, suggesting that physical habitat degradation has not been responsible for the deterioration of its bass population. We believe that this is the case for most streams in southwestern Wisconsin, and that instream physical habitat improvement will not substantially improve bass populations in this area. We feel that the deterioration of bass populations has not been caused by a gradual decline in the physical habitat conditions, but rather by short-term declines in chemical habitat (i.e., water quality) such as low dissolved oxygen, high ammonia, and/or elevated pesticide concentrations. These declines in water quality are usually associated with runoff events and probably reduce bass populations through immediate fish kills or through sublethal stresses that reduce reproduction and survival. We feel that these stresses, whether acute or sublethal, can be prevented through changes in land use and/or agricultural practices in the stream's watershed, but not by deepening pools or adding cover.

At the same time, we feel that plans should proceed for land acquisition along streams with existing bass fisheries and for subsequent management of the riparian zone to exclude cattle and ensure stable bank and riparian vegetation. The impacts of riparian vegetation on water quality are well-known and this first step toward protection of smallmouth bass fisheries can be easily justified.

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1 inch = 2.54 cm
1 ft = 30.48 cm or 0.3048 m
1 mile = 1.609 km
1 cfs = 0.028 cms
1 acre = 0.405 ha or 4.047 m^2
1 oz = 31.103 g
1 lb = 0.373 kg
1 cm^2 = 0.155 inch^2
1 g = 0.035 oz
1 liter = 33.83 oz

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