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UNITED STATES DEPARTMENT OF THE INTERIOR
Fish and Wildlife Service
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Division of Fishery Services
Mescalero, New Mexico

Special Report

FISHERY MANAGEMENT PROGRAM

Feasibility of Introducing Walleyes into the Caney River

Kansas

January 20, 1967

Special Report

Fishery Management Program

Feasibility of Introducing Walleyes into the Caney River Kansas

Introduction

A request for a study to determine the feasibility of introducing the walleye (Stizostedion vitreum) into the Caney River, Kansas, was made by Mr. E. J. Douglass, Chief, Division of Fish Hatcheries, in a memorandum dated March 21, 1966, to the Regional Director. Accordingly, on June 30 and July 1, 1966, field surveys were conducted on the Caney River near Elgin, Kansas, in cooperation with the Kansas Forestry, Fish and Game Commission.

The Caney River

The Caney River heads in Elk County and flows southward through Chautauqua County into Oklahoma where it joins the Verdigris River. The length of the Caney River in Kansas is approximately 55 miles. According to the United States Geological Survey, the average discharge in 27 years was 228 cubic feet per second at the gaging station near Elgin.

Survey of the River

Time did not permit a study of more than one station on the River during the summer of 1966. The lowermost and thus the largest part of the stream in Kansas was selected for study.

A one-mile reach of the River located just upstream from the county highway bridge west of Elgin was sampled with the Kansas Forestry, Fish and Game Commission's fish shocking unit. The unit was operated by Mr. Robert F. Hartmann, District Fisheries Biologist, Southeast District. He was assisted by Messrs. James Triplett and Everett Wilnerd, also of the Commission, and by Mr. Terrence J. Merkel of the Bureau of Sport Fisheries and Wildlife. The 115-volt AC shocking unit, with an electric boom system, was mounted in a 14-foot flatbottom boat powered by an outboard motor.

The reach of stream sampled consisted almost entirely of pools. The bottom was covered with a layer of fine silt and the water was highly turbid.

The following species were taken with the shocking unit:

Longnose gar (Lepisosteus osseus)
Gizzard shad (Dorosoma cepedianum)
Carp (Cyprinus carpio)
River carpsucker (Carpiodes carpio)
Smallmouth buffalo (Ictiobus bubalus)
Bigmouth buffalo (Ictiobus cyprinellus)
Black buffalo (Ictiobus niger)
Flathead catfish (Pylodictis olivaris)
Bluegill (Lepomis macrochirus)
Longear sunfish (Lepomis megalotis)
Freshwater drum (Aplodinotus grunniens)

It is probable that many other species were present although not taken in the sampling.

On July 1, 1966, at 10:45 a.m. temperature observations were made at a pool 0.5 mile upstream from the county highway bridge west of Elgin. The following data were recorded:

Water temperature (surface) - 84 degrees Fahrenheit
Water temperature (5 feet deep) - 82 degrees Fahrenheit
Air temperature - 84 degrees Fahrenheit

Discussion and Conclusions

The walleye is a species found mainly in large streams and lakes. It prefers clear water with gravel, bedrock, sand, or hard clay bottoms. In Ohio, increasing turbidity and the silting over of hard bottoms have been major factors in the decline of walleyes since 1900 (Trautman, 1957). Walleye populations can sustain themselves in waters approaching 90 degrees Fahrenheit (Kimsey, 1958). However, they generally prefer waters whose maximum temperature reaches 77 degrees Fahrenheit (Dendy, 1948).

Hulah Reservoir, 3600 surface acres, is located on the Caney River in Oklahoma just south of the Kansas-Oklahoma State line. Because of the silt problem in the Reservoir, the Oklahoma Department of Wildlife Conservation has not introduced walleyes.

The lower reach of the Caney River in Kansas does not appear to be suitable for walleyes because of silt and turbidity. Moreover, it is believed that the water temperatures at times exceed 90 degrees Fahrenheit. The headwaters of the Caney River are probably too small to support a walleye population but portions of the middle reach of the River in Kansas may be suitable.

Recommendations

It is recommended:

1. That walleyes not be planted in the lower reach of the Caney River in Kansas.

2. That a study be made to determine whether the middle reach of the Caney River in Kansas appears suitable for the introduction of walleyes. The study could be made by Bureau personnel in cooperation with Kansas Forestry, Fish and Game Commission personnel when the latter investigate the Caney River as part of the State-Wide Fisheries Survey (Federal Aid Project F-15-R-1).

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Factor Analysis of Distribution Patterns of Kansas Fishes

GERALD R. SMITH AND DAVID R. FISHER

ABSTRACT

The distribution patterns of fishes within Kansas were analyzed to determine (1) a small number of generalized patterns based on similarities of distributions and intended to summarize the available distributional data, and (2) correlations between distributions and environmental variables. Ninety-six drainage units in Kansas were assigned a value for each of 105 species of fishes. A 132 by 132 matrix of correlation coefficients between distributions of species and environmental variables was calculated; eight factors were extracted by the complete centroid method. Factor scores for each drainage unit were computed and plotted as trend-surface maps for each factor. Seven of the factors enable summarization of seven classes of fish distribution patterns and environmental patterns.

The generalized patterns are: (I) 21 species of large-river fishes; (II) 13 species of cool-water prairie and plains fishes; (III) 19 widespread prairie and plains species; (IV) 21 warm-water species with high correlations with environmental variables; (V) 10 species associated with the Osage River drainage; (VI) fishes with distributions centered in the Neosho River drainage—four species plus five with higher correlations with factor VII; (VII) fishes with Kansas distributions centered in the Spring River drainage in the southeast corner of the state—14 species plus seven species with higher correlations with other factors. Nineteen species independent of the factors had relatively unique distribution patterns.

INTRODUCTION

The pattern of distribution of a species will reflect limitation by existing environmental features as well as effects of past environmental features on the distribution and dispersal of ancestral populations. In this paper we describe and summarize the patterns of distribution of fishes in Kansas and attempt to analyze the environmental and historical influences on them. Our method is to arrange the distributional data objectively into a few generalized patterns and to look for correlations between patterns of environmental variables and fish distributions. Our working hypothesis is that one or more of the tested environmental variables will correlate with, and help explain, each distribution pattern in the study area. Two alternative possibilities are that nontested environmental variables or historical explanations are necessary to account for species patterns.

The usual approach to such a zoogeographical study involves the subjective assignment of species patterns into groups or units which presuppose an explanatory hypothesis. For example, a conceptual unit, "plains forms of southern origin," is assigned species patterns which, in the judgment of the investigator, fit such a category better than other categories. A disadvantage is imposed by the practice of assuming and including the explanatory hypothesis, for example, "plains forms of southern origin," as a descriptor of the group before assigning species to the group. Subsequent use of the phrase "plains forms of southern origin" as an explanatory conclusion might be subject to the criticism of circularity.

The method outlined below attempts to avoid the problems of subjectivity and circularity and to increase the repeatability of zoogeographic analysis (Fisher, 1968; Orloci, 1967). The generalized pattern groups are formed strictly on the basis of similarity of distribution in Kansas. The descriptors and summary statements for each group are suggested by the form of the generalized patterns and the known ecological requirements of the included species.

TREATMENT OF DATA

The basic data for this analysis consist of spot distribution maps of Kansas fishes compiled by Cross (1967). The study is restricted geographically because Kansas is one of few areas for which such thorough fish distributional maps are published. We subdivided a hydrographic map of the state into 96 drainage units of relatively consistent size—the largest being only several times the size of the smallest. The shape of the units was variable. Additional drainage units of similar size were drawn around the perimeter of the state and used to mollify the edge-effect of the trend-surface mapping program, but this is not an essential part of the analysis. A matrix of fish distributions by drainage units was composed by scoring each drainage unit for the presence or absence of each of 105 species of fishes known from more than one drainage unit in the state.

ENVIRONMENTAL VARIABLES

Data for 27 environmental variables were included in the above matrix by scoring each drainage unit for a value taken from trend-surface maps copied from sources as follows.

Geological substrate and elevation. —The 1:500,000 scale Kansas Geologic Map prepared by the State Geological Survey of Kansas (1937) was used as the basis for scoring each drainage unit for the presence or absence of nine variables. The strata used as variables are: (1) Carboniferous and Permian limestones, shales, etc.; (2) Permian Cimarron series (sandstone, dolomite, etc.); (3) Cretaceous Dakota group (sandstone, etc.); (4) Cretaceous Carlile shale; (5) Cretaceous Niobrara chalk; (6) Cretaceous Pierre shale; (7) Tertiary Ogallala group (sands, gravels, silts, etc.); (8) Pleistocene alluvium and terrace deposits. Elevation was recorded from the United States Relief Map (U.S. Geological Survey, 1929).

Temperature variables. — Trend-surface maps for the following data in Kansas were taken from Flora (1948): (1) length of growing season (number of frost-free days); (2) number of days in which the maximum temperature exceeds 90°F; (3) number of days in which the minimum temperature is less than 32°F; (4) number of days in which the maximum temperature is less than 32°F.

Precipitation and water variables.—Trend-surface maps for the following were taken from Flora (1948) and Miller *et al.* (1963): (1) average annual precipitation; (2) average annual runoff; (3) number of April–September dry periods (number of times during 45-year interval that 30 consecutive days passed with not more than 0.25 inch of precipitation on any day; (4) mean evapotranspiration; (5) mean lake evaporation; (6) hardness of surface waters (as ppm $CaCO_3$); (7) salinity of surface waters (measured as areas where surface waters may contain more than 1000 ppm of dissolved solids).

Drainage basin.—Correlations with individual major drainage basins (degree of endemism) were checked by including the following as variables in the matrix: (1) Kansas River drainage; (2) Osage River drainage; (3) Neosho River drainage; (4) Verdigris River drainage; (5) Arkansas River drainage; (6) Cimarron River drainage; (7) drainage of Missouri River and immediate tributaries.

FACTOR ANALYSIS

The basic data matrix consists of values for 132 fish distributions and environmental variables scored for each of 96 drainage units. A 132 by 132 correlation matrix was computed, giving the correlation between each of the distributional and environmental variables. Factor analysis—in this case, R-type factor analysis—is a method of reducing a large data matrix (here the 132 by 132 correlation matrix) to a smaller number of summarizing reference axes. The complete centroid method of Thurston (1945) was used for factor calculation because of the speed of the method and because of limitation of computation facilities when the study was begun. The number of factors to be extracted, eight, was determined by the method of Rohlf (1962). Extractions of six and 17 factors were also calculated, but six summarized the data too severely, with too much loss of information, and 17 factors failed to summarize concisely enough for our purposes. In these extraction exercises the same kinds of patterns—in some cases exactly the same patterns—emerged; they simply were divided up and expressed in more or less concise ways, with more or less information reduction. The eight factors were rotated to simple structure, using the method of oblique rotation (MTAM) developed by Sokal (1958). These factors are no longer uncorrelated. The method of Wilkinson and Householder (Ralston, 1965) was also used to extract eight factors. The differences provide an interesting comparison of the methods and a test of the repeatability of this kind of analysis.

Factor scores for each drainage unit were computed and plotted as sixth-degree trend-surface maps for each factor, using a program made available by John C. Davis of the Kansas Geological Survey. Lists of the individual distribution patterns correlated with each of the factors were compiled, using a correlation coefficient of .300 as the lower limit for inclusion of a species or environmental variable in a factor-group. Some species had higher correlation coefficients than .300 with more than one factor; 19 species were not correlated as high as .300 with any factor. Choice of .300 as the cut-off point is one of the arbitrary aspects of the analysis.

The factor-groups are summarizations based on similarity of distribution patterns and warrant explanatory generalizations. The 19 independent patterns require more specialized explanations. Tables 1-6, showing the degree of correlation between individual distribution patterns and some of the dominant environmental variables, enable analysis of the role of those variables in limiting the distribution patterns in each factor group.

GENERAL DISTRIBUTION PATTERNS AND ENVIRONMENTAL CORRELATIONS

The eight factor-groups extracted by Thurstone's complete centroid method summarize seven kinds of fish distributions and one pattern for the environmental variables. Trend-surface maps of the geographical patterns of factor loadings for each factor are shown in Figures 1 and 2. Two of the factor-groups, V and VI, are drainage-centered and suggest historical corridors of dispersal or origin for some of the species; group I reflects a unique habitat restriction; groups III and IV reflect environmentally determined distributions; groups II and VII reflect special historical-environmental interactions. Maps of the fish distributions referred to in the following discussion appear in Cross's (1967) *Handbook of fishes of Kansas*.

Factor I: Large river habitat.—Twenty-one species of Kansas fishes (Table 1, Figs. 1, 4) occur principally in large rivers in the state. The Missouri, Kansas, and Arkansas rivers provide the primary habitat for these fishes. The distribution patterns reflect the occurrence of this restricted, but relatively stable, habitat and are not usually correlated with climatic variables. It is interesting to note that most of the fishes belonging to relatively ancient families belong to this distributional group.

Factor II: Cool-water prairie and plains species.—Thirteen species are correlated with a pattern that centers primarily in northeastern Kansas, with a second cluster in the springs area at the contact between the Ogallala formation and underlying Cretaceous formations in northwestern Kansas. Twelve of the species are also correlated with one or more other factors, especially III (Table 2, Figs. 1, 4). The six primary members of this group are basically northern or cool-water species with inferred wider distribution in Kansas during times with more widespread cool-water habitat, but which are now common to areas fed by springs. They are isolated peripheral populations, the species-ranges of which presently are centered farther

TABLE 1. Species associated with factor I[*]

			Correlations with environmental variables							
Species[1]	Correlation with factor I	Correlation with other factors	Elevation	Number frost-free days	Number days reaching 90°F	Number days falling to 32°F	Annual Precipitation	Annual runoff	Lake evaporation	Pliocene Ogallala Formation
Ichthyomyzon castaneus	+	(VII:+)					+	+	—	
Acipenser fulvescens	++									
Scaphirhynchus platorynchus	++									
S. albus	+++									
Polyodon spathula	+	(V:+)								
Lepisosteus platostomus	+	(V:+)	—		—		+	+	—	
Hiodon alosoides	+									
Hybopsis gracilis	++									
H. storeriana	+									
H. meeki	+++									
H. aestivalis	+									
H. gelida	++								—	
Notropis shumardi	+++									
N. blennius	+									
Hybognathus nuchalis	+++									
Cycleptus elongatus	++									
Ictiobus niger	+		—		—	—	+	+	—	—
Ictalurus furcatus	+	(VI:+)								
Lota lota	+++									
Morone chrysops	+	(VII:+)								
Stizostedion canadense	++								—	

[*] Distribution in large rivers. The — or + indicates negative or positive correlation coefficient between 0.300 and 0.499; double symbols indicate values between 0.500 and 0.699; triple symbols indicate correlations higher than 0.700. Symbols in parentheses indicate existence of a higher correlation with another factor.

[1] Four additional species, *Lepisosteus osseus, Amia calva, Anguilla rostrata,* and *Ictiobus cyprinellus,* were added to this group when the analysis was run using the Wilkinson-Householder factor-extraction method. This method also showed this group to be correlated with the Missouri River drainage.

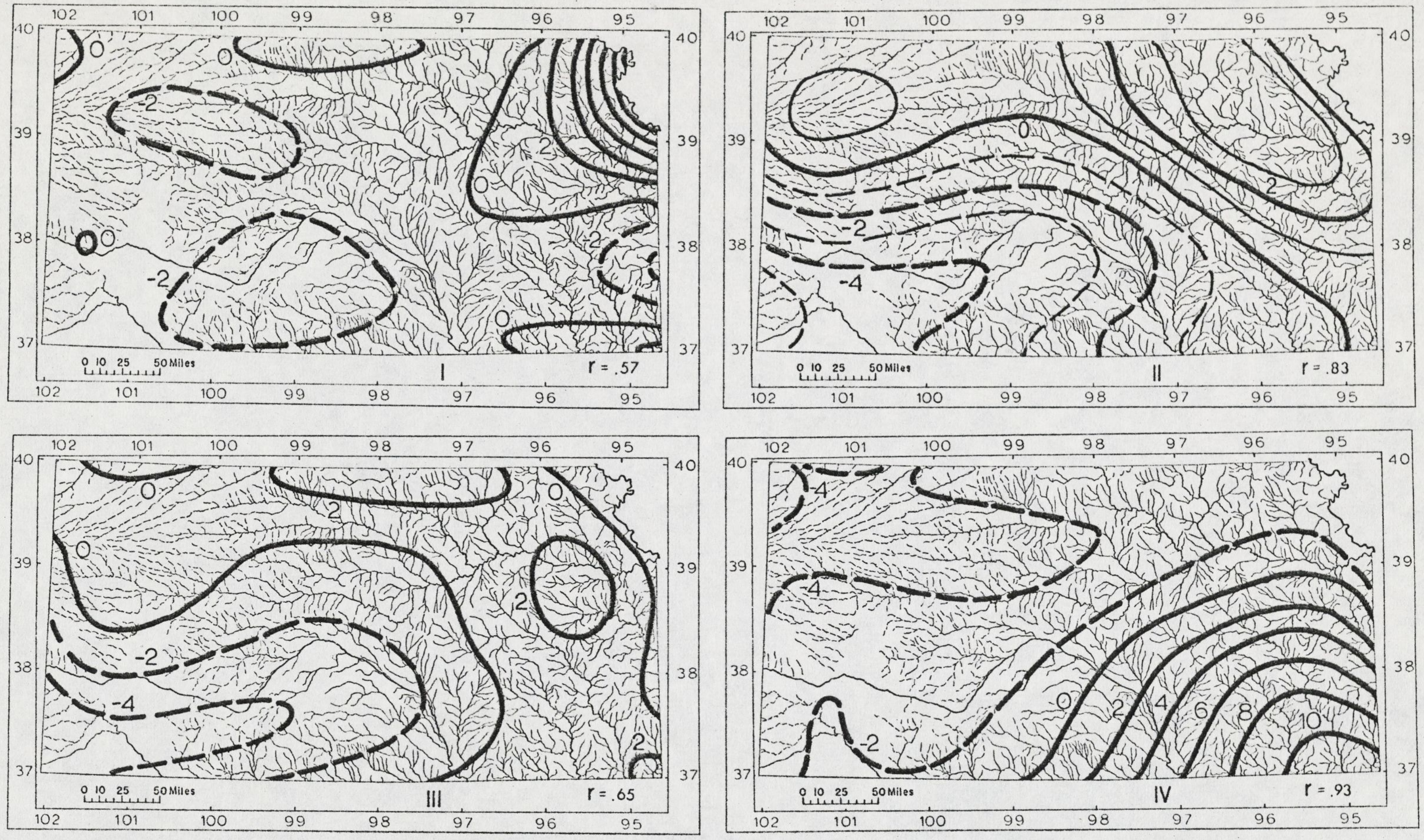

Fig. 1. Trend-surface maps of factor loadings for factors summarizing distribution patterns of fishes in Kansas. Factor I, large river species; factor II, cool-water prairie and plains species; factor III, widespread prairie and plains species; factor IV, warm-water species. The cophenetic correlation coefficient, *r*, reflects the degree to which the factor pattern is depicted by the trend surface.

north. There is a tendency for these species to be negatively correlated with the frequency of days exceeding 90°F and high lake evaporation (Table 2), further suggesting limitation of these species by historical reduction of the availability of permanent, cool-water habitat. The correlation between groups II and III ($r = .8$) suggests that II could be regarded as a subgroup of III.

Factor III: Prairie and plains species.—Nineteen species (Table 2, Figs. 1, 4) correlate with this factor; 11 of these are also correlated with factor II, and two of these are also correlated with factor IV. The pattern of factor III is interesting in that it is lacking in areas of high concentration. The species are inhabitants of prairie and plains streams and are widespread in Kansas. We suspect that the trend-surface pattern also reflects areas of collecting concentration. Some of the distributions, for example that of *Pimephales notatus,* are correlated with environmental gradients. *Fundulus kansae* is unique in that the signs of its correlations are the reverse of the usual pattern—its distribution appears to be affected in the opposite way by most environmental variables. The introduced carp, *Cyprinus carpio,* fell into this factor-group.

Factor IV: Warm-water species.—Twenty-one species (Table 3, Figs. 1, 4) are correlated with factor IV. Two of these are also correlated with factor VII. The species are southern in Kansas and show consistent high correlation with environmental variables, indicating that their present ranges are strongly affected by climate and water conditions. A favorable environment

TABLE 2. Species associated with factors II (northern) and III (prairie and plains streams)*

				Correlations with environmental variables							
Species	Correlation with factor II[1]	Correlation with factor III	Correlation with other factors	Elevation	Number frost-free days	Number days reaching 90°F	Number days reaching 32°F	Annual precipitation	Annual runoff	Lake evaporation	Pliocene Ogallala Formation
Cyprinus carpio		++									
Semotilus atromaculatus	(+)	+	(IV:+)			——					
Chrosomus erythrogaster	+		(VII:+)								
Phenacobius mirabilis	(+)	++		—				+	+		—
Notropis cornutus	+	(+)				—				—	
N. lutrensis	(+)	++		—				+	+		—
N. topeka	++	(+)									
N. stramineus		++			—						
Hybognathus placitus		+									
Pimephales promelas	(+)	++									
P. notatus		+		——	+		—	++	+	—	—
Campostoma anomalum	(+)	++		—				+	+	—	
Carpiodes carpio		+									
Catostomus commersoni	++	(+)	(IV:+)			—				—	
Ictalurus melas	(+)	++									
I. punctatus		+									
Fundulus kansae		+		+		+	+	—	—	+	—
Lepomis cyanellus		+		—			—	+	+		—
L. humilis	(+)	+				—			+	—	
Etheostoma nigrum	+					—				—	
E. spectabile	+	(+)		—	+	—		++		—	—

* Symbols as in Table 1.

[1] The species of groups II and III, excepting *Chrosomus erythrogaster* and *Catostomus commersoni,* were combined as one group when the factor-extraction was done with the method of Wilkinson and Householder.

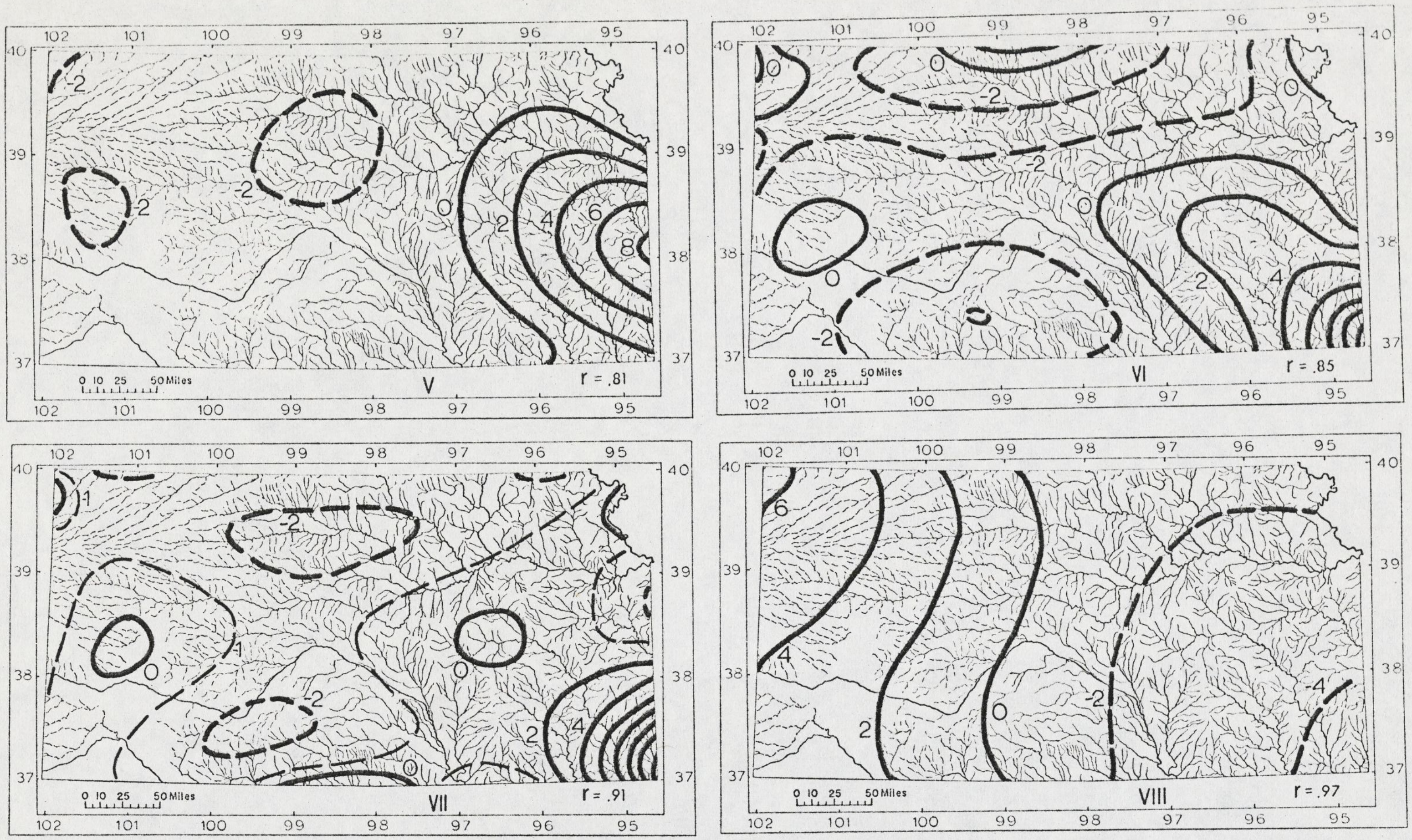

FIG. 2. Trend-surface maps of factor loadings for factor V, species centered in the Osage River drainage; factor VI, species centered in the Neosho River drainage; factor VII, species centered in the Spring River drainage; factor VIII, environmental variables.

TABLE 3. Species associated with factor IV—southern distribution patterns*

Species[1]	Correlation with factor IV	Correlation with other factors	Correlations with environmental variables: Elevation	Number frost-free days	Number days reaching 90°F	Number days reaching 32°F	Annual precipitation	Annual runoff	Lake evaporation	Pliocene Ogallala Formation
Dorsoma cepedianum	+		—	+		—	+	+	—	—
Notropis umbratilis	+		——	++	—	——	++	+++	—	—
N. boops	+	(VII:+)		+			+	+		
N. camurus	+++		—	++		—	+	+		
N. volucellus	++	(VII:+)	—	+		—	+	+		
N. buchanani	+		——	++	—	——	++	+++	——	—
Pimephales vigilax	++		—	++		—	+	+		
P. tenellus	++		—	++		—	+	++		
Ictiobus bubalus	+		—	+	—	——	++	++	—	—
Minytrema melanops	+		—	++		—	++	++	—	—
Moxostoma erythrurum	++		——	++		——	++	++	—	—
Fundulus notatus	++		—	++		——	++	++		
Gambusia affinis[2]	++			++		—		+		
Labidesthes sicculus	+++		—	++		——	++	++		+
Micropterus punctulatus	++		—	++		——	+	++		+
Lepomis macrochirus	+		—	+	—	—	++	++	—	—
L. megalotis	++		—	++		——	++	++	—	—
Percina phoxocephala	++		—	++		——	++	++	—	
P. caprodes	+		——	++		——	++	++	—	—
P. copelandi	++		—	+		—	+	++		
Etheostoma whipplei	+		—	+		—	+	++		

* Symbols as in Table 1.

[1] Factor-extraction by the method of Wilkinson and Householder included two additional species, *Noturus nocturnus* and *Etheostoma spectabile*, and two environmental variables, number of frost-free days (+) and number of days with the maximum temperature less than 32°F (—) with this group. *Opsopoeodus emiliae*, known in Kansas from one locality in the Verdigris drainage, was not included in the factor analysis, but belongs with this group.

[2] Range artificially extended northward by recent introductions.

TABLE 4. Species associated with Factor V—the Osage River distributions*

Species	Correlation with factor V	Correlation with other factors	Correlations with environmental variables: Elevation	Number frost-free days	Number days reaching 90°F	Number days reaching 32°F	Annual precipitation	Annual runoff	Lake evaporation	Pliocene Ogallala Formation
Polyodon spathula[1]	(+)	I:+								
Lepisosteus platostomus[1]	(+)	I:+	—		—		+	+	—	
Notemigonus crysoleucas	+		—	+		—	+	++	—	
Hybopsis biguttata	+				—		+	+	—	
Carpiodes velifer	+				—		+	+	—	
Hypentelium nigricans	(+)	VII:++					+	+		
Ictalurus furcatus	(+)	I:+							—	
Noturus gyrinus	+++									
N. nocturnus[1]	+			+		—	+	+		
N. exilis	++	(VII:+)	—		—	—	+	++	—	

* Symbols as in Table 1.

[1] Factor-extraction by the method of Wilkinson and Householder dropped these three species from this group.

TABLE 5. Species associated with factors VI (Neosho River) and VII (Spring River in Southeastern Kansas)[1]

				Correlations with environmental variables							
Species	Correlation with factor VI	Correlation with factor VII	Correlation with other factors	Elevation	Number frost-free days	Number days reaching 90°F	Number days reaching 32°F	Annual precipitation	Annual runoff	Lake evaporation	Pliocene Ogallala Formation
Ichthyomyzon castaneus		(+)	I:+					+	+	—	
Chrosomus erythrogaster		(+)	II:+								
Hybopsis x-punctata	+++	(+)		—	+		—	+	+		
Notropis pilsbryi	++	(+)							+		
N. boops		(+)	IV:+		+		—	+			
N. spilopterus		++							+		
Hypentelium nigricans		++	(III:+)					+	+		
Noturus exilis		(+)	V:++	—		—	—	+	++	—	
N. placidus	++	+	(II:+)	—	+		—	+	+		
N. miurus	(+)[3]	++			+				+		
Morone chrysops		(+)	I:+								
Micropterus dolomieui	(+)	+			+		—	+	+		
Chaenobryttus gulosus		+						+	+	—	
Ambloplites rupestris	(+)[3]	+++							+		
Pomoxis nigromaculatus		+									
Etheostoma chlorosomum	(+)[3]	+++						+	+		
E. zonale		++							+		
E. blennioides	(+)[3]	+++						+	+		
E. cragini		+				+					
E. flabellare	+	(+)			+		—	+	+		
E. gracile		++			+			+	+		

[1] Symbols as in Table 1. Eleven additional species were known from Kansas from one or two localities only and were not included in the factor analysis. *Dionda nubila, Moxostoma duquesnei, Fundulus sciadicus, Cottus carolinae, Etheostoma punctulatum,* and *E. microperca* are known in Kansas only from the Spring River and its tributaries, and belong to group VII. *Notropis chrysocephalus* (see Cross, this volume), *Percina shumardi, Etheostoma stigmaeum* are rare in the Neosho and Spring River drainages in Kansas, and can be regarded as members of group VII. *Lepisosteus occulatus* and *Hybopsis amblops* are known from single localities in the Neosho drainage (group VI).

[2,3] *Moxostoma carinatum* was added to group VII, and the species indicated [3] were dropped from group VI in the results of the factor-extraction using the method of Wilkinson-Householder.

for these species would appear to involve relatively low elevations, a long, warm growing season, and abundant permanent water. The broad pattern of these species suggests expanding range, as opposed to the contracting, relict ranges of factor-group II. Factor IV is relatively highly correlated ($r = .7$) with factor VI.

Factor V: Eastern species associated with the Osage River drainage.—Ten species (Table 4, Figs. 2, 5) are correlated with factor VI, but only six of these have their highest correlation with this factor. Six of the species are also correlated with either I or VII. The group includes a species restricted in Kansas to the Osage drainage, *Noturus gyrinus,* several species common in the Osage and adjacent tributaries to the Kansas River, and several large-river species for which the Osage drainage provides favorable habitat. A number of the species show high correlations with the environmental variables associated with abundant permanent water. It is possible that association with the Osage drainage is historically important to the dispersal of some of the species in this factor-group, but habitat appears to be the primary influence on these patterns.

Factor VI: Species associated with the Neosho River drainage.—Nine species (Table 5, Figs. 2, 5) are correlated with this factor; all of these are also

TABLE 6. Distribution patterns independent of factors I-VII*

Species	Factor with highest correlation	Correlations with environmental variables							
		Elevation	Number frost-free days	Number days reaching 90°F	Number days reaching 32°F	Annual precipitation	Annual runoff	Lake evaporation	Pliocene Ogallala Formation
Lepisosteus osseus	IV	—	+			+	++	—	—
Amia calva	I								
Anguilla rostrata	I								
Notropis atherinoides	I								
N. dorsalis[1]	I								
N. rubellus[2]	V	—	+	—	——	++	++	—	—
N. girardi	IV			+				+	
N. heterolepis[2]	IV								
Hybognathus hankinsoni[1,2]	I								
Ictiobus cyprinellus	I	—		—	—	+	+	—	—
Carpiodes cyprinus	III								
Moxostoma carinatum	VI		+		—	+	++		
M. macrolepidotum[2]	IV	——	+	—	—	++	++	—	
Ictalurus natalis[2]	III	—		—	—	+	+	—	
Pylodictis olivaris[2]	V								
Noturus flavus[2]	III	—		—	—	+	++	—	—
Micropterus salmoides[2]	V			—		+	+	—	
Stizostedion vitrium[2]	V								
Pomoxis annularis	III	—	+	—	—	++	++	—	—
Percina maculata[2]	II								
Aplodinotus grunniens[2]	V	—				+	+	—	—

* Symbols as in Table 1.

[1] Actually appeared correlated with factor I as a result of having been taken in small streams adjacent to the Missouri and Kansas rivers in Kansas.

[2] Species having no factor-group correlations higher than $r=.28$ in results of the Wilkinson-Householder method of factor-extraction.

correlated with factor VII. The distributions of these species in Kansas tend to be centered in the Neosho River drainage, suggesting a possible historical relationship to this drainage. The species are also consistently correlated with high annual runoff, indicating restriction to permanent streams. The correlation between factors VI and VII is high ($r=.8$).

Factor VII: Species associated with Spring River.—Twenty-one species (Table 5, Figs. 2, 5) are correlated with this factor; all but six of these are also correlated with some other factor or factors (an additional six species are limited in Kansas to Spring River and belong to this group, although they were not included in the computer analysis because they are known from one locality only). Spring River, in extreme southeastern Kansas, is a stream situated at the edge of the Ozark Highlands. Because of this, Spring River is the focal point in the distribution of Ozarkian fishes in Kansas. It is also in the vicinity with the highest climatic equability in Kansas (Fig. 3). These fishes show high correlations with environmental variables associated with permanent streams. Although the distribution of these fishes in Kansas is distinctly southern, they do not show the high degree of positive correlation with length of growing season that is characteristic of the members of group IV.

Factor VIII: Environmental variables.—The design of the analysis was intended to provide maximum opportunity for correlation between environmental variables and factor-groups.

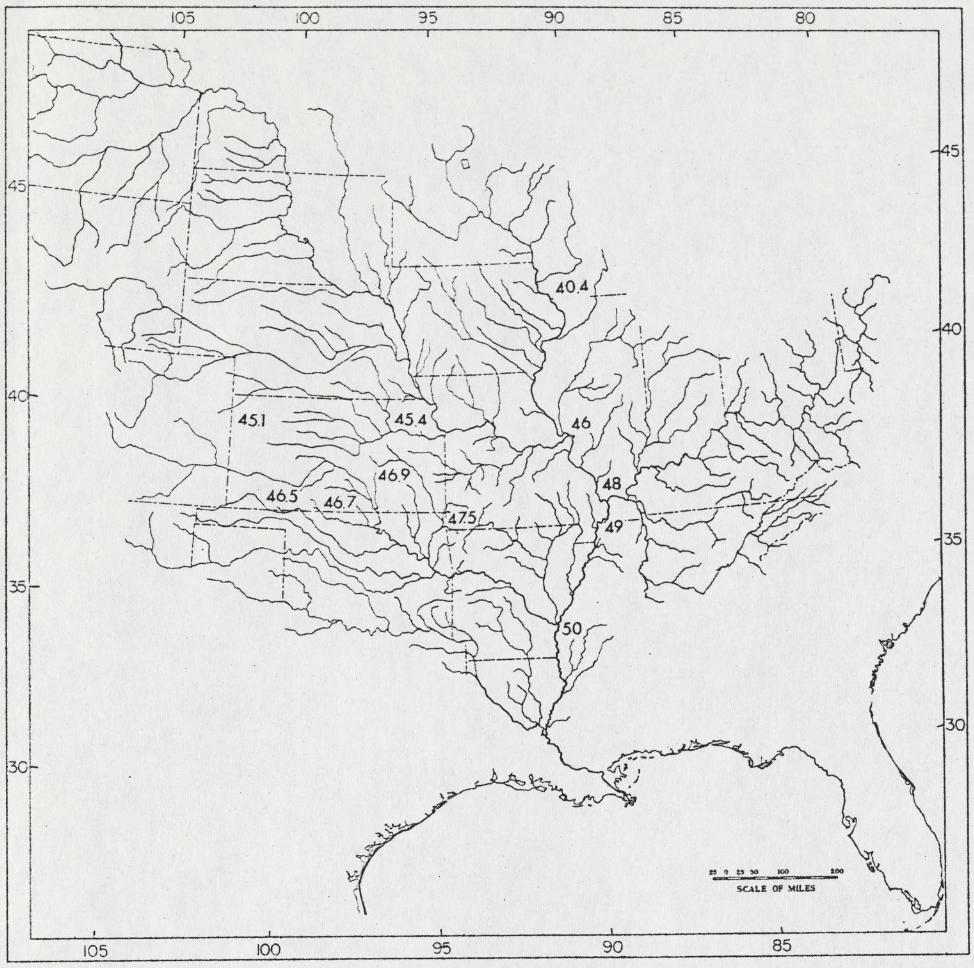

Fig. 3. Kansas is drained by the Kansas-Missouri system, which joins the Mississippi River at St. Louis, Missouri, and the Arkansas, which joins the Mississippi River in southeastern Arkansas. The figures give estimates of climatic equability, calculated according to Axelrod and Bailey, 1968.

However, the distribution patterns of environmental variables were more similar to each other (Fig. 2) than any was to any of the generalized factor distributions. The high correlations among environmental variables made it possible to select a smaller number as examples for expression in Tables 1-6.

The inclusion of major drainage patterns among the variables showed little about endemism or centers of dispersal relative to the factor-groups. The Neosho and Osage drainages as variables were highly correlated with factors VI and V, as expected. The Verdigris drainage is correlated ($r=.66$) with the warm-water factor-group (V). The prairie factor-group (III) is negatively correlated ($r=-.36$) with the Arkansas River drainage west of the Verdigris River, although all but one of the 19 species correlated with factor III occur in the Arkansas as well as the Kansas drainage.

Most of the fishes whose distributions appear highly correlated with climatic variables also show high positive correlations with the Carboniferous and Permian limestones and shales of eastern Kansas. Many of these species are negatively correlated with the Tertiary Ogallala group (sands, gravels, silts, etc.) of western Kansas. Limestone may contribute to the favorable habitat for these fishes through influence on bottom type, control of stream flow, and contribution to nutrient richness in the aquatic environments. The contact between the water-bearing Ogallala formation and the underlying aquicludes, the Niobrara chalk and the Pierre shale, provides spring-fed, permanent streams important to the distribution of plains fishes (Metcalf, 1966), including some of those in factor-group II and *Hybognathus hankinsoni,* which has a positive correlation ($r=.38$) with the Pierre shale.

Among the climatic variables tested, length of the growing season and annual runoff showed the highest, most consistent correlations with the largest number of fish distributions, and are interpreted to be the most influential limiting factors examined. Elevation and evaporation are negative limiting factors associated with the above.

Independent distributions.—Nineteen fishes have sufficiently unique distribution patterns that they were not highly correlated with the eight factors extracted by the complete centroid method (Table 6). However, six of these were allocated to groups by the method of Wilkinson and Householder (see below), and can be regarded as relatively nonconformable members of those groups. In addition, *Notropis atherinoides, N. girardi,* and *Carpiodes cyprinus* bear special relationship to a group associated with the Arkansas River drainage. *Notropis rebellus,* an upland stream species, is approximately equally correlated with factors IV, V, and VI ($r=.23$) and is highly correlated with environmental variables. *Ictalurus natalis* and *Noturus flavus* are clear-stream fishes of eastern Kansas with distributions otherwise correlated with factor III. *Moxostoma macrolepidotum* is a large-stream inhabitant of eastern Kansas, and its distribution is correlated with environmental variables. *Notropis heterolepis* has undergone recent range restriction (see Cross, this volume). The distributions of *Pylodictis olivaris, Micropterus salmoides, Stizostedion vitreum, Aplodinotus grunniens,* and perhaps *Ictaluris natalis* have been influenced by their occurrence in impoundments or their transport for fisheries in the state, which may account for their failure to sort out with the factor-groups. *Percina maculata,* limited (in Kansas) to clear streams in Wabaunsee and Riley counties, is clearly associated with factor-group II ($r=.25$). Three species on the "independent" list, *Notropis atherinoides, Notropis rubellus,* and *Moxostoma macrolepidotum,* are taxonomically complex and probably include more than one adaptive response to environmental limitation. The same may be true of others, including *Hybopsis aestivalis. Hybognathus hankinsoni* and *Notropis dorsalis* are limited to a few cool, sandy-bottomed streams in Kansas. Their highest correlations in this study were with factor I, but this is an artifact of their occurrence adjacent to the Missouri and Kansas rivers in northeastern Kansas. *Hybognathus hankinsoni* also shows relictual distribution in spring-fed headwaters of the Smoky Hill and Republican rivers in northwestern Kansas.

Competitive exclusion.—Correlations between species were searched for high negative values as indicators of possible competitive exclusion. The method is generally nonproductive because two of three possible expressions of such an interaction would not be recognized by correlations based on occurrence or absence in sample quadrats of the size used in this analysis. One possible type would involve species geographically sympatric but exclusive at the microhabitat level. A second would involve species with complementary distributions, but whose mu-

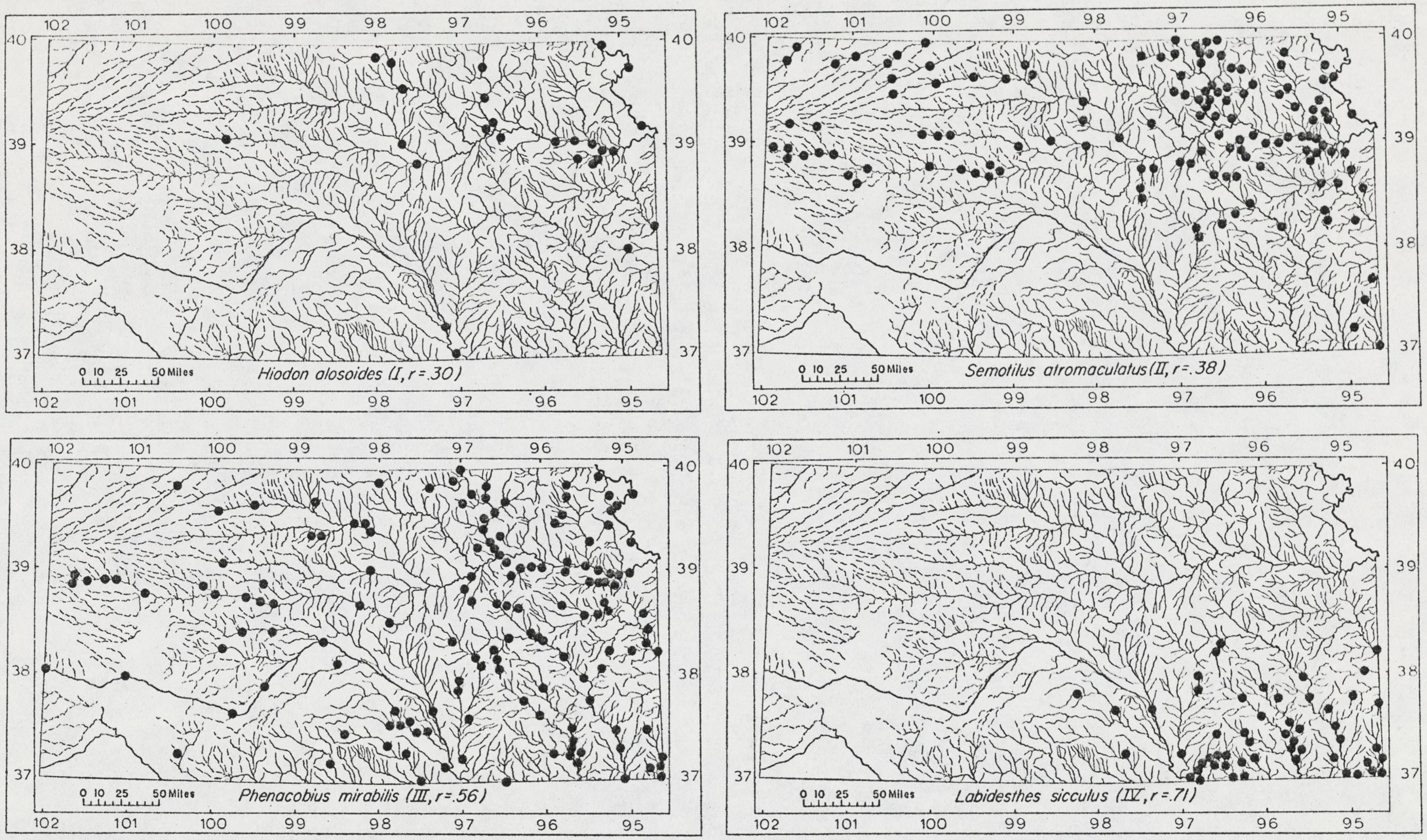

Fig. 4. Examples of species distributions representing factor-groups, I—*Hiodon alosoides,* II—*Semotilus atromaculatus,* III—*Phenacobius mirabilis,* and IV—*Labidesthes sicculus.* The *r* value gives the correlation between the species distribution pattern and the factor.

tual absence from a large part of the study area would depress the correlation coefficient. The noticeable form would involve two widespread species such as *Fundulus kansae* and *Fundulus notatus* (Fig. 5) whose ranges are largely complementary. The correlation coefficient for the distributions of these two species is —.24, and competitive exclusion might be involved.

TEST OF REPEATABILITY

The factor extraction was repeated with the method of Wilkinson and Householder (Ralston, 1965) to test the objectivity and repeatability of this analysis. Eight factor-groups appeared that corresponded to the eight factor-groups extracted by the complete centroid method, except that group II was included in group III and a new group was comprised of fish distributions in southern Kansas. The other seven groups corresponded well with those outlined in Tables 1 to 6, except as noted in the footnotes on those tables. The new group consists of forms found in the Arkansas River drainage in Kansas, including *Hybopsis aestivalis, Notropis atherinoides, Notropis girardi, Hybognathus placitus, Carpiodes cyprinus, Gambusia affinis, Etheostoma cragini, Fundulus kansae,* and the widespread species *Carpiodes carpio* and *Ictalurus punctatus*. High correlations suggest that the annual number of days over 90°F, salinity, absence of extreme cold (as measured by number of days with maximum less than 32°F), and some Arkansas River endemicity are causally related to this general pattern. (The extraction of six factors by the complete centroid method also deviated only in the recognition of this group, but without the two widespread species mentioned above or *Fundulus kansae*.) The environmental variables had relatively higher correlations among the eight fish factor-groups. The "independent" group was reduced from 19 to 10 distributions.

The method of Wilkinson and Householder is the more powerful of the two techniques used for factor extraction in this study. It is regarded as one of the "exact" methods, as opposed to the much faster "approximate" methods such as centroid. The results are comparable, however, and the centroid technique can be regarded as satisfactory for cases in which computation facilities or time are limiting. We conclude that factor analysis provides a direct and powerful tool for determining groups based on similarity of distribution and that the structure of these groups is largely independent of the method of factor extraction.

HISTORICAL ASPECTS

About 38 percent of the rich, fresh-water fish fauna of the Mississippi Basin is native to at least some Kansas waters. The major river systems draining Kansas—the Missouri and the Arkansas—join the Mississippi River several hundred miles to the east and southeast (Fig. 3). All but three of the 121 species native to Kansas have their geographical affinities to the east, northeast, or southeast, most of them in or near the center of the Mississippi Basin, a lesser number in the Ozark highlands, and a few each in the Missouri and Arkansas river basins. Forty-four species are restricted to either the Arkansas or Missouri systems in Kansas, but only 19 of these are so restricted when their entire range is considered. Five of these species are large-river inhabitants (group I) absent from the Arkansas River. Of the remainder, three are in the Kansas drainage, 11 are in the Arkansas drainage.

The general picture is one of distribution through the central confluence area of the Mississippi Basin (the dispersal "crossroads," as well as the

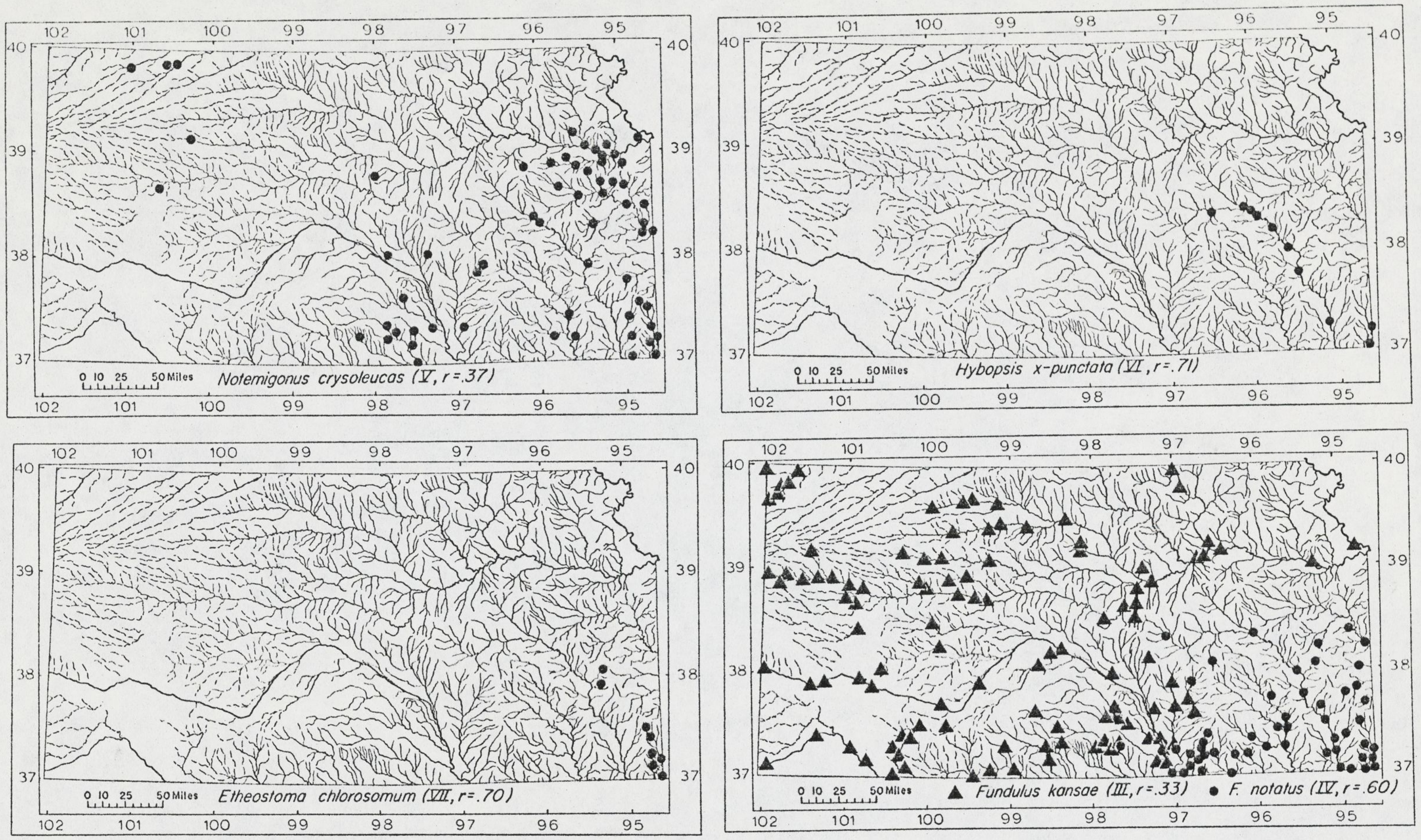

Fig. 5. Examples of species distributions representing factor-groups, V—*Note*and two complementary distributions, *Fundulus kansae* and *Fundulus notatus*.
migonus crysoleucas, VI—*Hybopsis x-punctata*, VII—*Etheostoma chlorosomum*,

area with the highest climatic equability, Fig. 3), with western range limitation primarily by elevation, climate, or habitat restriction, rather than by lack of access across divides. There is little evidence of differentiation of plains stream fishes in isolation by drainage divide barriers in western Kansas, and few instances in eastern Kansas. This indicates a history of significant faunal transfers accompanying stream captures in the evolution of the drainage basins, especially in the western half of the state. However, the distributions of several restricted species argue against the postulation of frequent drainage transfers. *Notropis cornutus,* in the east and west ends of the Kansas River drainage, and the southeastern species *Notropis camurus, Pimephales vigilax, P. tenellus, Micropterus punctulatus,* and *Percina phoxocephala* in the Arkansas drainage, have been found close enough to the drainage divide to be potential transfers, but remain restricted. The distribution of *Notropis cornutus* (group II) clearly argues against southward stream captures in the vicinity of its range during its present occupation (see Cross, this volume). However, considered in conjunction with the distribution of the many species on both sides of the divide, the pattern suggests relatively recent occupancy of the Kansas River drainage by *Notropis cornutus.* The type II distribution pattern of this species indicates dispersal into the present range during colder times. The period of access can be estimated as Wisconsin on the basis of the argument for recency plus the consideration that the upper Smoky Hill River, which it occupies, has been tributary to the Kansas River only since early Illinoian time (Bayne and Fent, 1963). The five southeastern species mentioned above all belong to factor-group IV, indicating primary limitation of their distribution in Kansas by length of growing season and permanence of stream flow. The distribution of *Percina phoxocephala* supports arguments against transfers from the Neosho and Marais des Cygnes (Osage) drainages into the Kansas, and the other three species weigh against transfers from the Neosho drainage to the Marais des Cygnes or Kansas drainages.

It is assumed in these arguments that if any of these six species gained access to the waters on the other side of the divides, their successful dispersal would not be limited by competition with species presently occupying the area. This is supported by the distributions of ecologically associated species that do occupy all major drainages in the vicinity. It is the distribution of these species, more than 36 of which have patterns that freely span the drainage divides in question, that suggests that the divides have not been significant barriers to the majority of the fauna. The well-documented transfer of the upper Saline and Smoky Hill rivers from the Arkansas to the Kansas drainage in early Illinoian time (Bayne and Fent, 1963) effected a significant northward faunal transfusion and probably allowed limited southward exchange for plains headwater species. Two endemics of the Arkansas drainage, *Notropis girardi* and *Etheostoma cragini,* are not found north of the Arkansas River on the plains and were probably unaffected by the shift of the divide.

In the above discussion, the terms divide and barrier have been used in the sense of the perimeter of the basin, which is uncrossed by aquatic habitat and fishes except by stream piracy. However, the first- and second-order streams near the perimeter of a basin are firstly, the streams most frequently involved in piracy and secondly, the environment of a distinctive headwater habitat characterized by higher elevation and smaller stream dimensions. In eastern Kansas, because of the relief and hard-rock substrate, the headwater habitat is also characterized by more rapid current and cooler waters; the reverse may hold in many environments of western Kansas. In either case it is clear that the headwater habitat provides an ecological barrier to some fishes (for example, group I in this analysis) and a habitable or optimum site for others (groups II and III), and thus directly determines their potential access to transfer by stream capture.

DISCUSSION

The numerous high correlations between individual distribution patterns and environmental variables further suggest the predominant potential of ecological explanations to account for fish distributions. Most systematically oriented investigations have traditionally sought historical explanations involving hypothetical past zoogeographic relations. The few patterns that are logically approachable owing to uniquely restrictive circumstances are highly interesting, but the vast majority of distributions lack logically useful historical controls and remain unsatisfactorily explained. Sources of ecological information remain generally unused, possibly owing to the lack of methods for detailed analysis and objective summarization. Environmental data were somewhat naively included in the present study to assay for patterns of correlation. The results suggest that a more detailed inclusion of more and better ecological data would enable more powerful explanations of distribution limits and patterns. Such general data as climatic equability and effective temperature (Axelrod and Bailey, 1968), soil types, nutrient availability, incident radiant energy, and the like, as well as more specific limnological data such as stream flow means and extremes, proportion of riffles and pools, daily temperature fluctuations, substrate, current, and the availability of benthic macroinvertebrates would be worth testing. Inclusion of specific environmental data would require concomitant collection of fish samples and would warrant inclusion of abundance estimates as well as data on trophic position and age structure. Past systematic sampling of localities has usually stressed effort to obtain the most complete listing of all, including rare, members of a taxonomic group to the exclusion of data on abundance and population structure. It might become necessary for collections also to include samples designed to reflect abundance and population structure, in addition to environmental data, for future zoogeographic studies. As regards paleozoogeography, if inferences to past climates are to use data on distribution and ecology of Recent faunas, then more detailed information on ecological limitation on Recent species is necessary.

CONCLUSIONS

Fishes occurring in Kansas can be divided into seven or eight groups based on similarity of geographical distribution in the state. The generalized patterns of these groups and the correlations between species ranges and environmental variables suggest possible environmental and historical explanations of fish distributions.

Group I includes 21 species, 17 percent of the native fauna, common to the distinctive habitat provided by large rivers. Five of these species do not occur in the Arkansas River, but the remainder are in both major drainages within the state. These species appear to be minimally influenced by the climatic variables tested, possibly because of the relatively stable and unique large-river habitat.

Group II is associated with group III, prairie and plains species, but emphasizes fishes requiring cooler waters. The most highly correlated members of this group are cool-water relicts whose distribution on the plains was more widespread in cooler, wetter times.

Group III encompasses prairie and plains species, most of which are widespread in Kansas. Few of the distributions are highly correlated with environmental variables. Most of the species occupy small streams and occur on the fringes of drainage basins, where they have probably been subject to transfer by capture of small streams during the evolution of the basins. A restricted exception is *Notropis cornutus,* limited to the Kansas drainage, which it probably invaded during Wisconsin time.

Group IV contains 21 species that have a generally southeastern distribution in Kansas but often more northerly limits in the center of the Mississippi Basin. High correlations suggest that these species are responsive to lower elevations, long and warm growing seasons, and abundance and permanence of water. Twelve of the species are excluded from the Kansas Basin, but only four of these penetrate the headwater habitat far enough to be available for transfer by small stream capture, and these four apparently ascend first-order streams but rarely.

Group V consists of a small group of species found, or formerly found, mainly in the Marais des Cygnes (Osage) drainage in Kansas. The Osage Basin has probably been especially important to the plains dispersal of some of these forms, but the historical and ecological interplay is unclear.

Group VI is made up of several species found in Kansas only, or primarily, in the Neosho drainage. These species are found in the larger streams in the basin and are probably limited by permanence of stream flow.

Group VII comprises a total of 28 species (or 23 percent of the native fauna) associated with Spring River, in the extreme southeastern corner of the state on the edge of the Ozark highlands. This area enjoys the highest climatic equability and supports the richest fauna in the state. At least 74 species of fishes have been collected in the Spring River drainage in Kansas. The 28 species of factor-group VII are Ozarkian species with Kansas distributions radiating out from a focal point in the Spring River corner. These species are not as dependent on growing season as are those of group IV, but are sensitive to stream permanence.

Several analyses of our data suggested the existence of another group of species—10 plains taxa with distributions widespread in the Arkansas drainage. Nineteen species have distinctive patterns not highly correlated with the factors. These species will require more specialized explanations, although nine of them were associated with factors when a more powerful analytic technique was employed. Several methods of factor analysis were tried and produced basically the same kinds of groupings, usually with essentially the same composition.

The Kansas fish fauna consists of Mississippi Basin fishes that range as far west as Kansas because they are adapted to either large rivers, the Ozark streams, or the prairie and plains streams, via the Arkansas or Missouri river drainages. The majority of the species occur in or near the center of the Mississippi Basin and occur in both the Kansas and Arkansas drainages. Drainage transfers have been effective in distributing at least those members of the fauna that inhabit streams near the edges of the basins.

Distributional evidence bearing on the centers of origin of the species of this fauna is virtually erased by the occupation of the central, climatically equable part of the Mississippi Basin by many species that might have arisen elsewhere and by the dominance of ecological factors in the determination of species limits. Nineteen species are restricted to the Arkansas or Kansas basins; however, some unknown but significant number of these were not so restricted in earlier times in the Pleistocene (see Cross, this volume). Only one species in Kansas is distinctly western. There is little direct evidence in the fish distribution patterns to suggest that other members of the fauna had western origins separate from the Mississippi Basin (but see Metcalf, 1966).

Considering that the habitation of Kansas waters by fresh-water fishes is a matter of individual degrees of adaptation to a continuum of environmental conditions, it is perhaps surprising that the distribution patterns do indeed fall into groups based on similarity. The nature of the drainage is such that fishes have had dispersal access to Kansas waters by groups; but in fact, the generalized patterns reflect ecology more than they reflect dispersal routes. It appears that solid data bearing on distribution are to be found in fossil occurrences and ecology; speculations on centers of origin and dispersal remain difficult.

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