LANDSCAPE-SCALE INFLUENCES ON
STREAM FISH ASSEMBLAGES
IN EASTERN OKLAHOMA

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CHAPTER I

This thesis is composed of one manuscript written in a format suitable for publication in the North American Journal of Fisheries Management. This manuscript is complete without supporting materials. Chapter I is an introduction to the rest of the thesis. Chapter II is the manuscript, entitled “Landscape-scale influences on stream fish assemblages in eastern Oklahoma.”

CHAPTER II

LANDSCAPE-SCALE INFLUENCES ON STREAM FISH ASSEMBLAGES IN EASTERN OKLAHOMA

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Abstract

Ecoregions are commonly used as a starting point for regional management planning and conservation applications. The objective of this study was to relate watershed characteristics to stream fish assemblages among aquatic ecoregions and stream types in eastern Oklahoma. We compiled fish collection data from three studies in eastern Oklahoma, and filled data gaps by seining streams that were not represented in these collections. Watershed and stream characteristics were compiled and summarized using a geographic information system. Differences in stream and watershed characteristics and fish assemblage parameters among ecoregions were analyzed with analysis of variance and least significant difference multiple comparison test. Cluster analysis and detrended conical correspondence analysis (DCCA) were used to identify stream groups and relationships between species assemblages and watershed characteristics.

The Ouachita Mountains had the highest mean annual precipitation and was dominated by forest. The Ouachita also had the greatest topographic relief and valley slopes. Shale was the predominant rock type in the Ouachita Mountains and in the other southern ecoregions. The Arkansas Valley and Central Irregular Plains were predominantly low relief, low slope sandstone basins with land use dominated by prairie and agriculture. Limestone was dominant in the Ozark Highlands with the Boston Mountains containing limestone and shale. These ecoregions also had high topographic relief, woodlands and prairie.

We identified four clusters: Ozark streams, plains streams, Ouachita streams, and low gradient streams. Only the Ouachita group coincided with aquatic ecoregional boundaries. This group organized along gradients of geology and land use. The Ozark streams, low gradient streams and plains streams, however, grouped together regardless of the ecoregion in which they occurred. Ecoregions, while having some relationship to stream fish assemblage structure, may serve as the best template for regional fish management. To adequately capture fish assemblage patterns and issues, one must delineate management regions specific to streams, with a clear understanding of landscape characteristics, stream channel conditions, habitat features and the scale at which each these influence stream fish assemblage structure.

Introduction

Stream systems develop in a nested hierarchy where landscape elements influence local conditions (Frissell et al. 1986). Landscape features such as geology and topography (Nelson et al. 1992, Richards et al. 1996, Frissell et al. 1986), climate and land use (Schlosser 1991; Waite and Carpenter 2000; Maret et al. 1997, Imhof et al. 1996), and stream flow (Rabeni and Sowa 1996; Poff et al. 1997; Aadland 1993) provide the environmental setting in which local conditions, such as stream habitat, develop. It is at the local scale that fish assemblage organization occurs (Frissell et al. 1986).

The geology and topography of a watershed directly influence channel morphology and the distribution and abundance of stream organisms. Frissel et al. (1986), Richards et al. (1996) and Rosgen (1996) indicated that geology controls channel morphology through sediment composition and availability. Richards et al. (1996) found that geology affected streambed structure, thereby affecting macroinvertebrate and fish distribution through the distribution of available habitat .Rosgen (1996) developed a classification system in which stable stream morphologies could be predicted by valley type. For example, an alluvial valley was expected to exhibit stable meandering streams with low slopes. In contrast, notched canyon valleys were expected to exhibit stable streams with step/pool morphology and steep slopes. Geology and topography also influence the amount and pattern of stream flow (Richards et al. 1996; Poff et al. 1997). Richards et al. (1996) found that slope and geology had the strongest influence on the intensity of flood events. Slope also influences the rate at which water moves across the soil as overland flow. Balkenbush and Fisher (1999) hypothesized that the flashiness and high intensity of flood events in the Glover River, Oklahoma, exacerbated by intensive silviculture and steep slopes in the Ouachita Mountains, contributed to high mortality and poor growth in smallmouth bass (*Micropterus dolomieu*), resulting in lower standing stock.

Watershed vegetation and land use shapes instream habitat (Frissell et al. 1986) by influencing surface runoff (Imhof et al. 1996) and channel structure (Osborne and Kovacic 1996; Richards et al. 1996). Changes in land use such as conversion to row crops, deforestation and grazing affect the dynamic equilibrium of streams and can reduce large woody debris, stream depth, substrate type, and habitat diversity (Schlosser 1991). Schlosser also found that these land use changes were associated with a decrease in pool habitat and large piscivores, and an increased rate of water and sediment delivery making high and low flow events more intense. Riparian buffer areas may temporarily moderate nutrient and sediment inputs into a stream, but long-term water quality is more strongly correlated with the land use of the entire watershed (Richards et al. 1996).

Watershed vegetation composition and intensity of land use impacts fish assemblages. Maret et al. (1997) found the percent of forested watershed to be a useful predictor of fish distributions, as was watershed size and valley slope. Waite and Carpenter (2000) compared fish assemblage structure to watershed characteristics In medium-sized streams in the Willamette Basin, Oregon, and found an increase in introduced species and external parasites and abnormalities in watersheds with a combination of agricultural and urban land uses.

Ecoregions establish a logical basis for characterizing ecosystems based on the concept that the landscape features used to delineate ecoregions are the causal factors that determine the potential types of ecosystems within an ecoregion (Omernik 1987). Ecoregions are often used as the starting point for macroscale-level analysis to group stream systems, particularly for biomonitoring (Hughes et al. 1994). Fisher et al. (in press) used aquatic ecoregions as a basis for developing fisheries management regions in eastern Oklahoma. Using physical and biological data, they clustered ecoregions into stream fisheries management regions, forming a basis for stream fisheries management in eastern Oklahoma. The Nature Conservancy used ecoregions as a basis for conservation planning for both streams and terrestrial communities (TNC 2000).

The objective of this study was to relate differences in watershed characteristics to stream fish assemblages among aquatic ecoregions and stream types in eastern Oklahoma.

Methods

Study Area

The Interior Highlands physiographic province covers roughly the eastern quarter of Oklahoma. The western boundary of the province runs along the Grand-Neosho River, across Lake Eufaula and along the Kiamichi River watershed (Figure 1). This region encompasses portions of six ecoregions (Omernik 1987, Table 1): Ozark Highlands, Central Irregular Plains, Boston

Mountains, Arkansas Valley, Ouachita Mountains, and Central Oklahoma-Texas Plains.

The Ozark Highlands are an uplifted Mississippian limestone dome (Warth and Polone 1965) with fluviokarstic hydrologic processes . The fractured limestone bedrock creates cave systems and spring-fed losing streams alternating between surface and sub-surface flow. Land use consists of agriculture, confined animal feeding operations and silviculture (Omernik 1987). The Ozark Highlands are similar to the Boston Mountains, which form its southern border; however, the Boston Mountains have more sandstone bedrock and are more mountainous than the Ozark Highlands.

The Arkansas Valley in east-central Oklahoma is a low-relief shale basin (Cederstrand 1996a-c) dominated by oak-hickory and oak-pine forests (Omernik 1987). The Arkansas River, draining the northern half of Oklahoma, runs through the middle of this ecoregion. The dominant land use is agriculture.

The Ouachita Mountains is a high relief area with shale basins and sandstone and igneous outcroppings (Suneson and Hemish 1994). It is dominated by oak-pine forest, and a large portion of the ecoregion is part of the Ouachita National Forest. The Little River and Kiamichi River drain the Ouachita Mountains. Silviculture is the predominant land use with agriculture and confined animal feeding operations in the floodplains (Fisher et al. 1997).

The Central Oklahoma-Texas Plains is a low-relief ecoregion dominated by crosstimbers and tallgrass prairie. The eastern portion is predominately shale, with alternating bands of sandstone (Cederstrand 1996a-c). The dominant land use is agriculture.

Data Compilation

Fish assemblage data were compiled from various sources and supplemented with field collections. Sources of fish collection data were the Oklahoma Department of Environmental Quality (DEQ, Tejan and Fisher 2001), Rutherford (1988), and Martinez et al. (1996). Fish were collected using various methods. The DEQ and Martinez et al. (1996) conducted surveys in the summer and fall by seining all available habitat types in 100-m stream segments. Rutherford (1988) sampled 100-m lengths of stream using a backpack electrofisher (AC generator, 220 v 12 amp; hand held electrodes) followed by seining. Only fish collections made after 1980 were used in the analyses.

To fill in gaps in these collections, we sampled 39 sites on 16 streams in eastern Oklahoma during the summer and fall of 1999 and 2000 (Figure 2). Collections were made by seining every available habitat in 100-m stretches of stream. We used a 10-m seine with 6.5-mm mesh. Fish were identified and enumerated in the field, and voucher specimens were preserved in 10% formalin and verified in the lab. In all, we compiled data from 434 collections on 139 rivers, streams and springs in eastern Oklahoma.

Spatial watershed data were obtained in a digital format at a scale of 1:100,000, when available, from various agencies. The River Reach File 3a hydrology data (U.S. Environmental Protection Agency 1998) were used as the basis for measuring stream features. A statewide digital elevation model

(Cederstrand and Rea 1996) was used to calculate topographic relief and valley slope and to generate watershed boundaries. Precipitation data, complied in a digital grid model (Rea and Tortorelli 1997), were used to determine mean annual rainfall in watersheds. Surficial geology (Cederstrand 1996a-c) was obtained from the U. S. Geological Survey. Land cover data was obtained from the Oklahoma Gap Analysis Project (OK-GAP; Fisher and Gregory 2001) and reclassified into broader categories. Information was extracted from these datasets and assigned to reach watershed for sample sites. These data were entered into a relational database and combined for use in statistical analyses.

Analyses

Ecoregion variation.—We compared stream reach and watershed characteristics and fish assemblage structure among ecoregions. Stream reach characteristics were evaluated using valley slope and network position, indicated by downstream link (d-link) (Shreve 1967). Downstream link identifies the size of stream that a reach flows into, and was chosen due to it's power in predicting fish assemblage structure as compared to stream order or (Osborne and Kovacic 1996). Watershed characteristics included land cover, geology, precipitation, topographic relief (represented by the standard deviation of elevation), and road density. Land cover was generalized into five categories: forest (vegetation dominated by trees greater than 5 meters tall with 61-100% canopy cover), woodland (vegetation dominated by trees over 5 meters tall with 26-60% canopy cover), prairie (dominated by herbaceous plants), agriculture land, and urban areas. Surficial geology was grouped into four rock types: limestone, shale, sandstone, and alluvium. Fish assemblage structure was compared using species richness (the total number of species per site), the numbers of introduced and native species and the number of species in the families Cyprinidae, Centrarchidae, Percidae, and Catostomidae.

We used a Kruskal-Wallace test of ranked data (Steele et al. 1996) to compare stream reach and watershed characteristics and fish assemblages among ecoregions. Differences between specific ecoregions were detected using Least Significant Difference (LSD) contrasts with a Bonferroni-Dunn correction ($\alpha = 0.05$).

Stream classification. — Ward's cluster analysis was used to group streams into classes based on presence or absence of fish species at each site. We used Ward's pseudo t^2 values to help determine cluster groups. We used Detrended Canonical Correspondence Analysis (DCCA; CANOCO software; Jongman et al. 1995) to detect patterns in fish assemblages and their relationships to environmental gradients. DCCA is a multivariate ordination technique that arranges sites along axes based on species composition, accounting for environmental relationships. The DCCA axes represent linear combinations of environmental variables and species scores along which the sites are plotted. With this analysis, one can determine the relative importance or unimportance of environmental gradients in determining species composition. We used presence or absence of fish species at each site, and stream reach and watershed characteristics to determine species associations and environmental relationships. To determine which environmental variables were driving site clustering, the sites were ordinated along environmental axes using DCCA.

Results

Ecoregional variation.—In general, land cover ranged from forest in the Ouachita Mountains and Boston Mountains to woodlands, prairie and agriculture in the Arkansas Valley, Central Irregular Plains and Ozarks (Table 2). The Ouachita Mountains had the greatest amount of forest, the Central Oklahoma-Texas Plains and the Boston Mountains had moderate amounts, and the Ozark Mountains, Central Irregular Plains and Arkansas Valley had the least amount. The northern ecoregions (Ozark Highlands, Central Irregular Plains, Boston Mountains and Arkansas Valley) had more woodlands and prairie than the southern ecoregions (Ouachita Mountains and Central Oklahoma–Texas Plains). Agricultural lands dominated the landscape in the Arkansas Valley, Central Irregular Plains, Ozark Highlands and Central Oklahoma-Texas Plains, the Boston Mountains had moderate amounts, and the Ouachita Mountains had the least.

Surficial geology differed among ecoregions (Table 2). Limestone was dominant in the northern ecoregions (Ozark Highlands and Central Irregular Plains). The Boston Mountains had a mix of limestone and shale. Shale was the predominant rock type in the Ouachita Mountains and in the other southern ecoregions. The Arkansas Valley and Central Oklahoma-Texas Plains were predominantly sandstone.

Two of the three stream reach characteristics differed among ecoregions (Table 2). Valley slopes in the Ouachita Mountains, Ozark Highlands and Boston Mountains were greater than those in the Central Oklahoma–Texas Plains, Prairie, and Arkansas Valley ecoregions. D-link was similar across most ecoregions, with the only significant difference being between the Boston Mountains, which had the highest d-link and the Ouachita Mountains had the lowest d-link. Cumulative watershed size did not differ among ecoregions.

Topographic relief was the greatest in the Ouachita Mountains, which was similar in this respect to the Boston Mountains and Ozark Highlands (table 2). The Central Oklahoma-Texas Plains, Arkansas Valley and Central Irregular Plains had less topographic relief. The Ouachita Mountains had the highest mean annual precipitation and differed from all other ecoregions; in contrast, the Central Irregular Plains Arkansas Valley had the lowest annual precipitation.

Fish assemblage structure also differed among ecoregions (Table 3). Species richness and total number of native species per site were the highest in the Central Oklahoma-Texas Plains which differed from all other ecoregions except the Boston Mountains. The Boston Mountains had the greatest number of introduced species, followed closely by the Ozark Highlands and the Central Irregular Plains. The Arkansas Valley, Central Oklahoma-Texas Plains and the Ouachita Mountains had the least number of introduced species.

The Boston Mountains had the greatest number of cyprinid species, and was similar to the Ozark Highlands, Central Oklahoma-Texas Plains and the Central Irregular Plains (Table 3). The Ouachita Mountains and Arkansas Valley had the least number of cyprinid species. Centrarchid species were most common in Central Oklahoma-Texas Plains and least common in the Ozark Highlands and Central Irregular Plains. Percid species richness was greatest in the Boston Mountains and least in the Ouachita Mountains. Catostomid species richness was similar among all ecoregions.

Stream Classification.—Four clusters of stream types were identified based on cluster analysis: Ozark streams, Ouachita streams, plains streams and low gradient streams (Figure 3).

The DCCA had specie-environment correlations of 0.893 for the first axis and 0.636 for the second axis indicating that most of the variation in fish assemblage structure was accounted for by the environmental variables (Table 5). The first two axes accounted for 65.9% of the variation between sites. Axis one was interpreted to be most influenced by precipitation and limestone. Axis two was influenced primarily by network position, forest and agriculture (Table 6).

Ozark streams were located primarily in limestone watersheds with a mixture of forest and woodlands (Table 4, Figure 4) and had a predominance of cardinal shiners (*Luxilus cardinalis*), banded sculpins (*Cottus carolinae*), Ozark minnows (*Notropis nubilis*), and southern redbelly dace (*Phoxinus erythrogaster,* Figure 5).

Ouachita streams were dominated by shale and forest and located in the region with the highest annual rainfall. These streams had small watersheds and were positioned high in the stream network. Species found at most Ouachita streams included: orangebelly darters (*Etheostoma radiosum*), grass pickerel

(*Esox americanus*), yellow bullhead (*Ameiurus natalis*), and creek chubsucker (*Erimyzon oblongus*; Figure 5).

Low gradient streams generally had large watersheds and shallow slopes, with watershed features such as geology or land use being less important (Figure 4). The most common fish were gizzard shad (*Dorosoma cepedianum*), freshwater drum (*Aplodinotus grunniens*), longnose gar (*Lepisosteus osseus*), and smallmouth buffalo (*Ictiobus bubalus*; Figure 5).

Plains stream sites did not cluster together and were distributed along both axes 1 and 2. They showed a weakly positive relationship with slope and percent limestone. Because the plains streams did not cluster, fish assemblage relationships are inconclusive (Figure 4). Widespread species, those that were common to many sites grouped near the origin of the DCCA axes. These included bluegill (*Lepomis macrochirus*), warmouth (*Chaenobryttus gulosus*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), spotted bass (*Micropterus punctulatus*), black redhorse (*Moxostoma duquesnei*), central stoneroller (*Campostoma anomalum*), and golden shiner (*Notemigonus crysoleucas*; Figure 5).

Discussion

Despite the popularity and success of using ecoregions as a starting point for fisheries and ecosystem management (Hughes et al. 1994; TNC 2000; Fisher et al. *in press*), the applicability of ecoregions in predicting stream fish assemblages has been found to be limited (Hughes et al. 1994, Maret et al.

1997; Newall and Magnuson 1999). Omernik's (1987) aquatic ecoregions were developed using a combination of aquatic and terrestrial patterns. Ecoregional boundaries, created for general planning purposes, were not intended to be a precise fit for any one faunal group or other similarly narrow application.

Our analysis of eastern Oklahoma stream fish assemblages revealed four groups; only one of which, the Ouachita group, agreed with aquatic ecoregion boundaries (Omernik 1987). The Ouachita group was aligned along the first axis: positively associated with precipitation, but negatively associated with limestone. The Ouachita streams had forested watersheds with shale geology, coinciding with the Ouachita Mountains ecoregion.

The Ozark streams, low gradient streams and plains streams, however, did not correspond well with ecoregional boundaries. These stream types grouped together regardless of the ecoregion in which they occurred. The lack of agreement between ecoregion boundaries for Ozark streams, low gradient streams and plains streams suggests that ecoregions might be a poor predictor of fish assemblage structure for these stream types.

Ozark streams included those with limestone geology and a mixture of woodland and prairie land use, including streams in both the Ozark Highlands and Boston mountains ecoregions. Cross et al. (1986) hypothesized that the zoogeographic distributions of several Ozark species (*Phoxinus erythrogaster*, *Notropis nubilis*, and others) resulted from the Kansan glaciation. These species previously had more widespread distributions, but did not reinvade their historic ranges after retreat of glaciers because glacial till did not provide suitable habitat.

The Ozark stream group identified in our analysis showed similarities to the faunal boundaries created by this glaciation event. This suggests that zoogeographic barriers may be a more important predictor of fish assemblages than ecoregional boundaries.

In the case of low gradient streams, stream size and valley slope seem to be important factors. Wilkinson and Edds (2001) analyzed stream fish communities and their relationship to environmental factors in the Spring River, which covers parts of two ecoregions in southeast Kansas: the Ozarks and Central Irregular Plains. They determined that, similar to our results, there was a clear difference between Ozark streams and plains streams. Moreover, they concluded that it was necessary to separate the lower section of the Spring River (a low gradient river) into its own group, irrespective of ecoregion. Newall and Magnuson (1999) found no relationship between stream fish community structure and ecoregions in the St. Croix River basin. Rather, they found that drainage area had a strong association with fish community structure and that the predictable changes in flow regime and channel morphology associated with increased stream size had ultimate control over community structure.

Plains streams included mostly lowland stream sites in the Arkansas and Red River basins and some steep slope Ozark Highland and Boston Mountain streams. These sites were spread along both DCCA axes, with a clump of steep sloped streams having high scores on axis 2 and positively associated with forested lands (Figure 4; Table 6). This suggests that the environmental variables most influencing these stream sites were not included in the analysis. Maret et al. (1997) observed a similar pattern in their comparison of stream fish assemblages and environmental variables within four ecoregions in the upper Snake River basin of Idaho and Wyoming. They found overlap in fish assemblages among ecoregions, and concluded that elevation and major topographic features, such as waterfalls, controlled assemblage structure.

Ecoregions, while having some relationship to stream fish assemblage structure, may not be best indicator of fish management regions because of wide variation in stream types and fish assemblages in an ecoregion (Toepfer et al. 1998). As stated by Omernik (1987), ecoregions are designed for multipurpose planning efforts, not for any specific biological group. Therefore, managers must take this into consideration and, if necessary, delineate management regions specific to their needs. To adequately capture fish distribution patterns, these regions must be delineated according to stream type with a clear understanding of zoogeography, landscape influences including land use, climate and geology, local influences including network position and valley slope, and the scale at which each of these factors influence stream ecosystem structure. ,

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Table 1. Aquatic ecoregions of eastern Oklahoma based on Omernik (1987).

Ecoregion	Land-surface Form	Potential Natural Vegetation	Land Use	Soils
Ozark Highlands	Open hills, high hills	Oak/hickory, Oak/hickory/pine	Mosaic of Cropland, Pasture, Woodland and Forest	Ultisols
Central Irregular Plains	Irregular plains	Mosaic of bluestem prairie (bluestem, panic, indiangrass) and oak/ hickory	Cropland with grazing land, cropland	Mollisols
Boston Mountains	Low mountains	Oak/ hickory	Forest and woodland grazed	Ultisols
Arkansas Valley	Plains with hills	Varied forest types (vs. Prairie): oak/ hickory/ pine, southern floodplain forest (oak, tupelo, bald cypress)	Cropland with pasture, woodland and forest	Alfisols, sandstone/ shale soils
Ouachita Mountains	Open high hills to open low mountains	Oak/hickory/pine	Forest and woodland grazed	Moist ultisols
Central Oklahoma-Texas Plains	Irregular Plains	Crosstimbers (Oak, bluestem) mosaic of bluestem prairie (bluegrass, panic, indiangrass) and Oak hickory	Cropland with pasture, woodland and forest	Alfisols

Table 2. Stream watershed characteristics for eastern Oklahoma ecoregions.

Ecoregion and parameter	Forest (%)	Woodlands (%)	Prairie (%)	Agriculture (%)
Ozark Highlands (N=73)				
Mean	36.0 c	13.3 a	21.3 a	29.2 a
SD	21.0	5.3	97.0	14.7
Range	1.7 – 79.0	6.3- 43.2	5.3- 52.8	5.9- 70.4
Boston Mountains (N=48)				
Mean	47.3 bc	12.6 a	17.5 a	18.2 b
SD	20.7	5.6	8.4	10.6
Range	1.0- 84.3	0- 30.1	2.7- 34.8	0- 46.5
Central Irregular Plains (N=38)				
Mean	30.7 c	11.6 a	22.6 a	33.0 a
SD	24.0	4.6	9.8	16.8
Range	0.5- 78.5	3.9- 26.9	0- 41.9	0- 62.7
Arkansas Valley (N=25)				
Mean	29.0 c	11.2 a	21.5 a	37.5 a
SD	18.9	5.3	7.6	16.9
Range	3.2- 71.0	3.3- 25.7	7.8- 34.0	10.9- 68.4
Ouachita Mountains (N=98)				
Mean	79.6 a	6.6 b	4.1 b	9.7 c
SD	17.5	4.9	4.3	11.8
Range	11.9- 100	0- 30.6	0- 26.8	0- 50.8
Central Oklahoma-Texas Plains (N=43)				
Mean	57.6 b	6.9 b	10.3 c	24.7 ab
SD	22.2	2.9	7.7	16.4
Range	15.4- 97.5	1.7- 13.7	0- 38.7	0.4- 56.7

Table 2. Continued.

Ecoregion and parameter	Limestone (%)	Shale (%)	Sandstone (%)	Precipitation (cm)
Ozark Highlands				
Mean	78.4 a	5.3 c	0 d	44.1 c
SD	25.3	11.4	0	1.1
Range	0- 100	0- 48.0	0- 0	42- 45
Boston Mountains				
Mean	45.9 b	2.9 c	12.1 c	44.4 c
SD	37.2	9.5	29.1	0.6
Range	0- 100	0- 45.7	0- 100	43- 46
Central Irregular Plains				
Mean	74.7 a	3.7 c	3.7 cd	43.5 d
SD	31.5	9.2	10.8	1.1
Range	0- 100	0- 51.4	0- 48.2	41- 45
Arkansas Valley				
Mean	0 d	32.8 b	47.5 a	44.2 cd
SD	0	42.8	44.2	1.1
Range	0- 0	0- 100	0- 100	42- 47
Ouachita Mountains				
Mean	0 d	53.1 a	18.5 b	51.0 a
SD	0	35.7	28.1	1.9
Range	0- 0	0- 1	0- 100	45- 55
Central Oklahoma-Texas Plains				
Mean	2.4 c	20.2 b	26.6 ab	48.4 b
SD	4.7	25.6	28.4	1.5
Range	0- 24.3	0- 89.2	0- 91.4	45- 50

Table 2. Continued.

Ecoregion and parameter	Topographic relief (m)	Downstream Link	Valley Slope	Watershed size (ha)
Ozark Highlands				
Mean	16.9 abc	116.8 ab	6.5 ab	28,035 a
SD	6.4	168.7	10.7	57235.0
Range	0.6- 28.45	2- 543	0- 75.9	2.2- 212334.8
Boston Mountains				
Mean	21.7 ab	264.7 a	6.0 ab	92,460 a
SD	12.2	269.6	10.0	114,053.5
Range	2.1- 59.56	2- 804	0- 64.9	8.6- 342308.9
Central Irregular Plains				
Mean	15.5 cd	114.7 ab	9.96 ab	9,354 a
SD	7.4	186.2	25.6	18185.2
Range	1.8- 32.79	2- 545	0- 126.2	2.52- 101696.0
Arkansas Valley				
Mean	12.4 cd	158.5 ab	3.1 b	62,010 a
SD	9.7	312.4	3.6	136,108.3
Range	0.5- 30.97	5- 990	0- 13.6	13.0- 424831.7
Ouachita Mountains				
Mean	26.3 a	84.6 b	6.1 a	24,579 a
SD	6.4	148.3	5.2	48,847.4
Range	0- 91.64	2- 745	0- 33.3	0.4- 254553.5
Central Oklahoma-Texas Plains				
Mean	11.2 d	117.1 ab	2.9 b	54296 a
SD	18.5	160.1	3.1	100,889.6
Range	0.5- 31.23	1- 706	0- 13.8	524.5- 319168.8

[1] Letters that differ between ecoregions indicate significantly differences.

Table 3. Fish assemblage characteristics for eastern Oklahoma ecoregions.

Ecoregion and parameter	Species richness	Native species	Introduced species	Cyprinid Species	Centrarchid species	Percids species	Catostomids Species
Ozark Highlands							
Mean	13.3 b	13.3 b	0.2 a	5.5 a	2.2 c	2.2 ab	0.9 a
SD	11.0	10.6	0.6	3.8	2.6	1.7	1.9
Range	1- 52	1- 50	0- 3	0- 17	0- 11	0- 7	0- 8
Boston Mountains							
Mean	17.6 ab	17.2 ab	0.4 a	6.5 a	3.1 bc	2.7 a	1.7 a
SD	14.3	13.6	0.8	4.4	2.9	1.6	2.6
Range	2- 52	2- 49	0- 3	0- 17	0- 10	0- 6	0- 10
Central irregular plains							
Mean	13.6 b	13.6 b	0.3 ab	4.7 ab	2.5 c	2.5 ab	1.0 a
SD	14.5	13.9	0.7	5.1	3.1	2.1	1.8
Range	1- 71	1- 68	0- 3	0- 26	0- 11	0- 9	0- 7
Arkansas Valley							
Mean	11.0 b	10.9 b	0.1 b	3.5 b	2.3 bc	2.0 ab	0.4 a
SD	0.2	9.6	1.6	3.3	2.0	2.4	1.3
Range	1- 56	1- 53	0- 3	0- 17	0- 9	0- 11	0- 6
Ouachita Mountains							
Mean	12.4 b	12.4 b	0.01 b	3.9 b	3.3 b	1.8 b	0.6 a
SD	9.8	9.8	0.1	2.9	1.7	2.4	1.1
Range	1- 70	1- 70	0- 1	0- 23	0- 11	0- 17	0- 7
Central Oklahoma-Texas Plains							
Mean	20.1 a	20.1 a	0 b	5.2 ab	5.5 a	3.0 ab	0.9 a
SD	15.4	15.2	0	5.1	3.1	3.5	0.9
Range	2- 86	2- 85	0- 0	0- 22	0- 15	0- 19	0- 4

[1] Letters that differ between ecoregions indicate significantly differences.

Table 4. Environmental variables from DCCA axes one and two for site groupings identified by Ward's cluster analysis.

Stream type and parameter	Valley Slope	Watershed size (ha)	Downstream link	Forest (%)	Woodland (%)
Low gradient streams (N=28)					
mean	1.26	159124.13	460.14	43.05	10.35
SD	2.45	117560.05	229.05	22.76	5.55
Range	0-12.3	29.88-424831.68	18-990	6.35-93.4	0-24.44
Ozark streams (N=90)					
mean	5.70	35896.35	125.48	39.01	13.05
SD	11.83	68486.31	182.07	19.49	4.15
Range	0-110.9	2.88-297345.24	2-797	0.95-78.49	5.85-26.53
Ouachita streams (N=119)					
mean	5.73	18720.53	61.87	76.14	5.98
SD	4.88	46807.60	106.10	19.64	3.96
Range	0-33.3	0.36-298710.01	1-627	21.20-100	0-30.56
Plains streams (N=97)					
mean	7.67	33224.38	120.92	40.05	11.30
SD	16.81	84561.97	212.54	27.75	6.36
Range	0-126.2	2.16-422033.76	2-984	0.53-100	0-43.18

Table 4. Continued.

Stream type and parameter	Agriculture (%)	Prairie (%)	Limestone (%)	Shale (%)	Precipitation (cm)
Low gradient streams (N=28)					
mean	24.71	17.42	22.48	5.21	45.42
SD	17.15	7.77	27.42	9.32	3.06
Range	0 – 62.20	2.20-31.25	0-92.88	0-31.12	42-55
Ozark streams (N=90)					
mean	26.37	20.57	68.78	4.88	44.05
SD	12.61	7.19	33.36	11.61	1.01
Range	2.73 – 63.92	5.25-34.83	0-100	0-47.99	42-45
Ouachita streams (N=119)					
mean	12.88	4.98	0.56	46.27	50.42
SD	14.27	4.70	2.63	36.26	1.91
Range	0 – 56.59	0-22.4	0-24.25	0-100	44-54
Plains streams (N=97)					
mean	28.82	18.27	41.20	15.12	45.05
SD	19.06	11.83	44.38	30.05	2.36
Range	0 – 19.06	0-52.81	0-100	0-100	41-53

Table 5. Parameters from the DCCA of species and environmental variables in eastern Oklahoma streams.

Parameter	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalue	.396	.067	.036	.010
Species-environment correlations	.893	.636	.511	.402
Cumulative percentage variance:				
Species only	12.8%	14.9%	16.1%	16.4%
Species-environment	56.3%	65.9%	71.0%	72.5%

Table 6. Environmental gradient loadings for the DCCA axes of streams and environmental variables in eastern Oklahoma. Values in bold (>0.300) were used to interpret axes 1 and 2.

Variable	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	.396	.067	.036	.010
Forest	.026	**.459**	-.381	-.317
Woodland	.154	.120	-.228	-.096
Prairie	.115	.187	-.267	.121
Agriculture	-.117	**.317**	-.011	-.405
D-link	-.007	**-.510**	.083	.023
Watershed size	.053	-.113	-.067	-.106
Topographic relief	-.026	.047	-.322	.013
Limestone	**.403**	.071	-.194	.351
Shale	-.103	.022	-.235	-.201
Valley slope	.063	.162	.018	.173
Precipitation	**-.546**	-.060	-.059	.545

Table 7. Fish species collected in eastern Oklahoma streams.

Number	Common name	Scientific name
1	Banded darter	*Etheostoma zonale*
2	Banded sculpin	*Cottus carolinae*
3	Bigeye shiner	*Notropis boops*
4	Black redhorse	*Moxostoma duquesnei*
5	Blackspotted topminnow	*Fundulus olivaceus*
6	Blackstripe topminnow	*Fundulus notatus*
7	Bluegill	*Lepomis macrochirus*
8	Bluntnose minnow	*Pimephales notatus*
9	Brook silverside	*Labidesthes sicculus*
10	Bullhead minnow	*Pimephales vigilax*
11	Cardinal shiner	*Luxilus cardinalis*
12	Central stoneroller	*Campostoma anomalum*
13	Channel catfish	*Ictalurus punctatus*
14	Channel darter	*Percina copelandi*
15	Common carp	*Cyprinus carpio*
16	Creek chub	*Semotilus atromaculatus*
17	Creek chubsucker	*Erimyzon oblongus*
18	Dusky darter	*Percina sciera*
20	Emerald shiner	*Notropis atherinoides*
21	Fantail darter	*Etheostoma flabellare*
22	Flathead catfish	*Pylodictis olivaris*
23	Freckled madtom	*Noturus nocturnus*
24	Freshwater drum	*Aplodinotus grunniens*
25	Gizzard shad	*Dorosoma cepedianum*
26	Golden redhorse	*Moxostoma erythrurum*
27	Golden shiner	*Notemigonus crysoleucas*
28	Grass pickerel	*Esox americanus*
29	Green sunfish	*Lepomis cyanellus*
30	Greensided darter	*Etheostoma blennioides*
31	Inland silverside	*Menidia audens*
32	Kiamichi shiner	*Notropis ortenburgeri*
33	Largemouth bass	*Micropterus salmoides*
34	Largescale stoneroller	*Campostoma oligolepis*
35	Logperch	*Percina caprodes*
36	Longear sunfish	*Lepomis megalotis*
37	Longnose gar	*Lepisosteus osseus*
38	Mimic shiner	*Notropis volucellus*
39	Northern hogsucker	*Hypentelium nigricans*
40	Northern studfish	*Fundulus catenatus*
41	Orangebelly darter	*Etheostoma radiosum*
42	Orangespotted sunfish	*Lepomis humilis*
43	Orangethroat darter	*Etheostoma spectabile*
45	Pirate perch	*Aphredoderus sayanus*

Table 7. Continued.

Number	Common name	Scientific name
46	Red shiner	*Cyprinella lutrensis*
47	Redear sunfish	*Lepomis microlophus*
48	Redfin/redspot darter	*Etheostoma whipplei/artesia*[1]
49	Redfin shiner	*Lythrurus umbratilis*
50	Redspot chub	*Nocomis asper*
51	River carpsucker	*Carpiodes carpio*
52	River redhorse	*Moxostoma carinatum*
53	Rock bass	*Ambloplites rupestris*
54	Rocky/carmine shiner	*Notropis sutkussi/percobromus*[2]
55	Slender madtom	*Noturus exilis*
56	Smallmouth bass	*Micropterus dolomieu*
57	Smallmouth buffalo	*Ictiobus bubalus*
58	Southern redbelly dace	*Phoxinous erythrogaster*
59	Spotted bass	*Micropterus punctulatus*
60	Spotted gar	*Lepisosteus oculatus*
61	Spotted sunfish	*Lepomis miniatus*
62	Steelcolor shiner	*Cyprinella whipplei*
63	Stippled darter	*Etheostoma punctulatum*
64	Striped shiner	*Luxilus chrysocephalus*
65	Warmouth	*Lepomis gulosus*
66	Wedgespot shiner	*Notropis greenei*
67	Western mosquitofish	*Gambusia affinis*
68	White bass	*Morone chrysops*
69	White crappie	*Pomoxis annularis*
70	Yellow bullhead	*Ameiurus natalis*

[1] *E. whipplei* of the Arkansas River Basin and *E. artesia* of the Red river basin were treated as a single taxon

[2] *N.percobromus* of the Arkansas River basin and *N. sutkussi* of the red river basin were treated as a single taxon.

Figure 1. Study area showing Omernik ecoregions, major rivers and reservoirs, and counties in eastern Oklahoma.

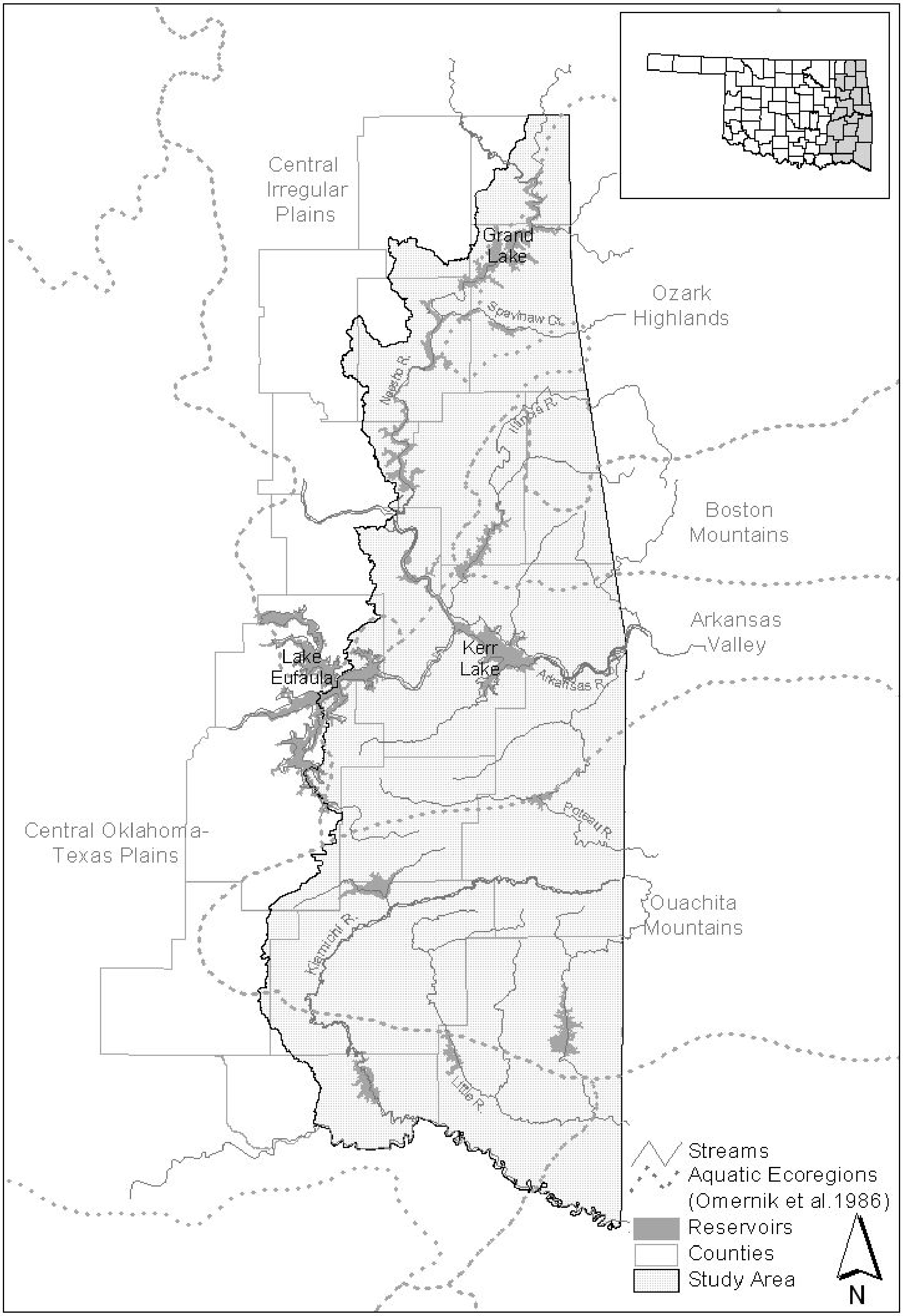


Figure 2. Streams sampled by Martinez et al. (1995), Rutherford (1988), the Department of Environmental Quality (DEQ; Tejan and Fisher 2001), and this study.

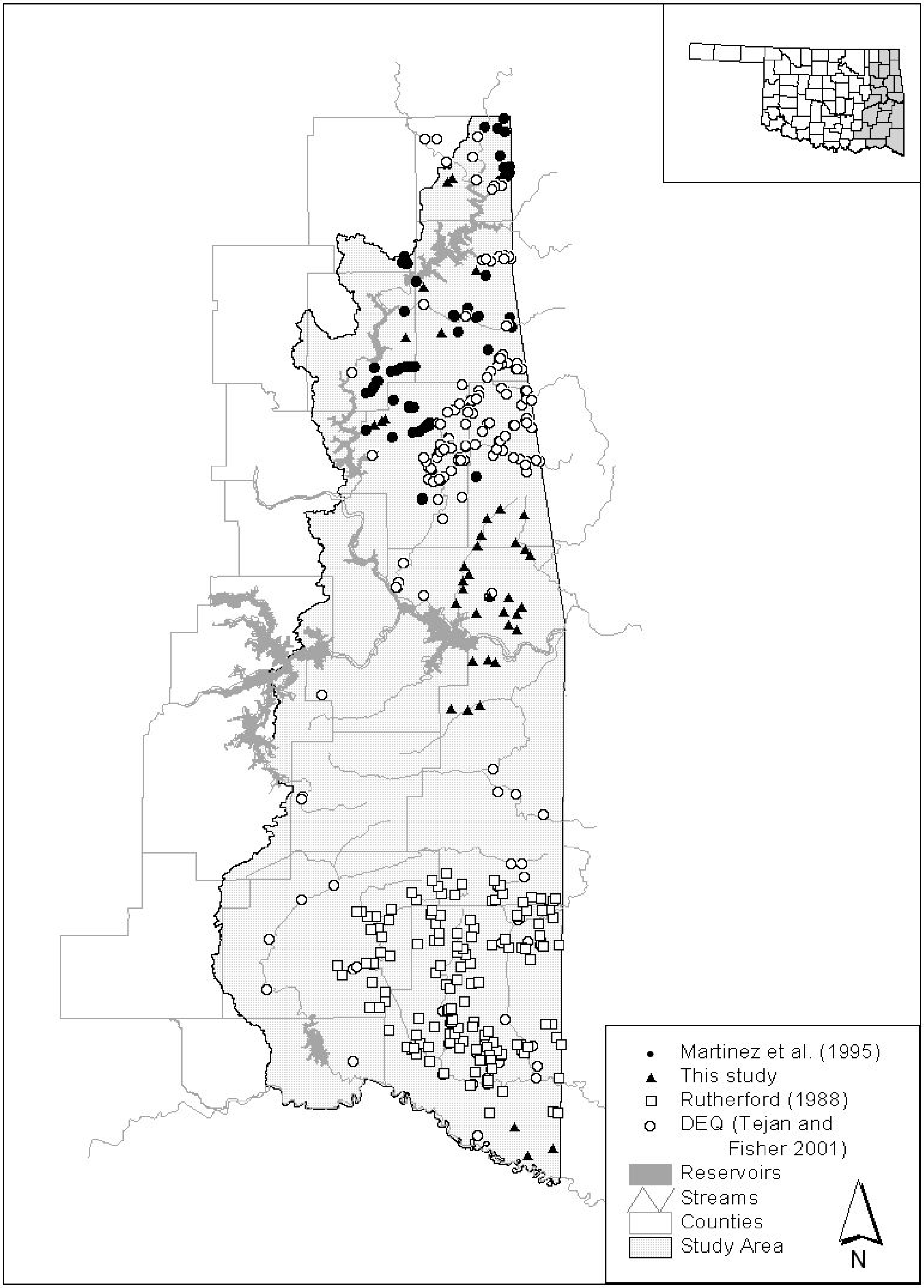


Figure 3. Spatial distribution of stream groupings resulting from cluster analysis of fish collections in eastern Oklahoma.

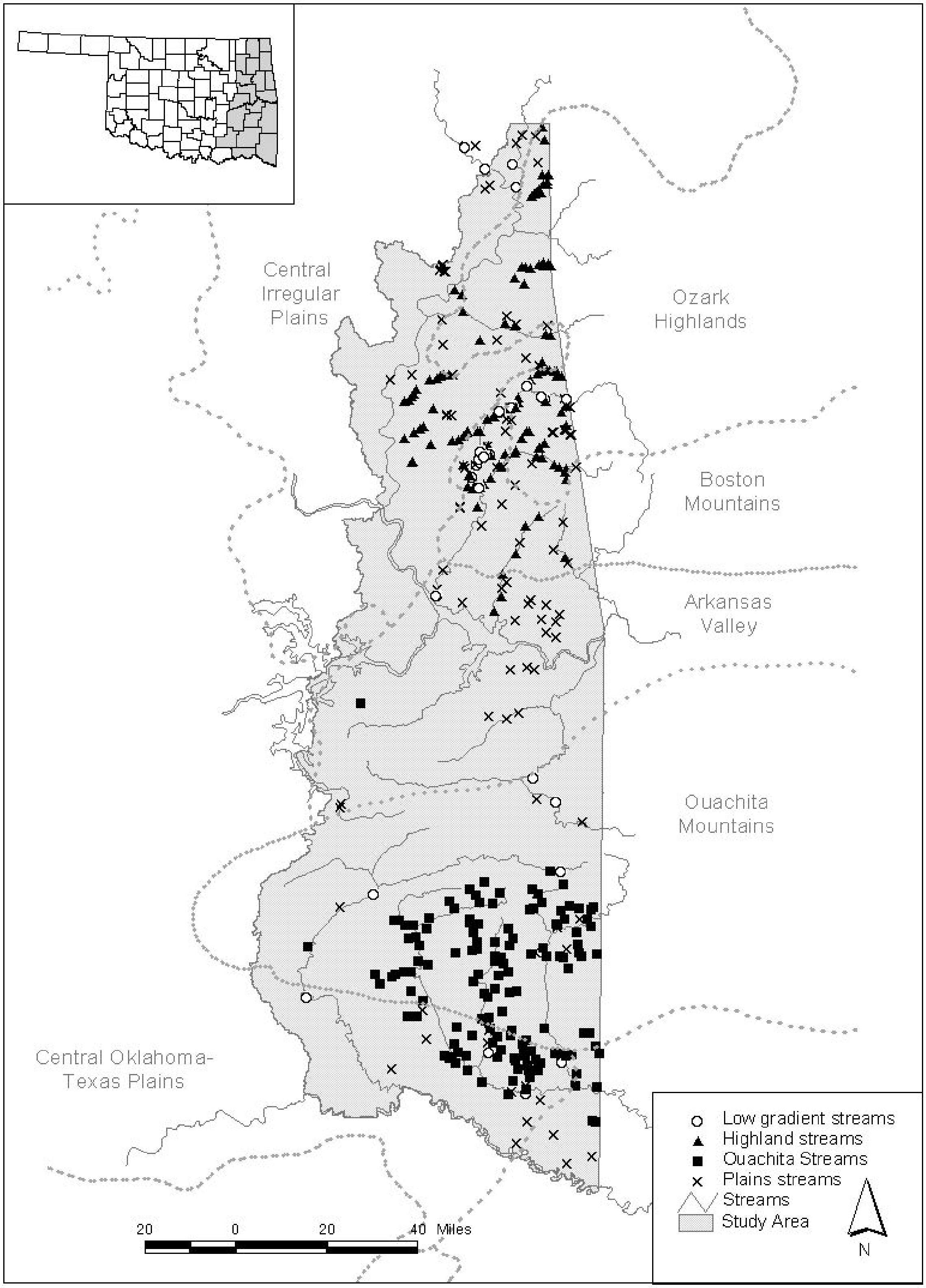


Figure 4. Detrended canonical correspondence analysis of streams sites in eastern Oklahoma. Symbols represent groupings based on cluster analysis.

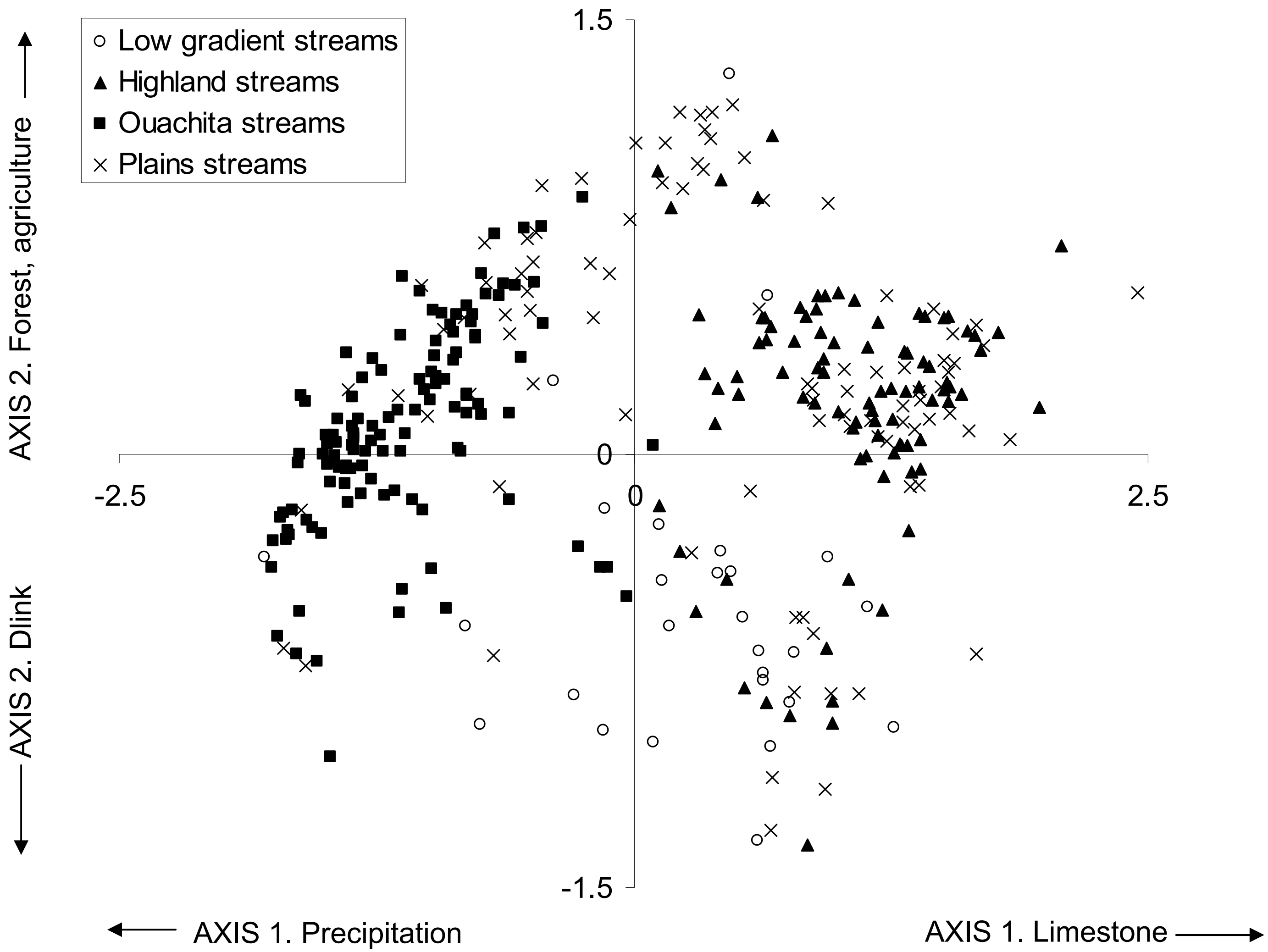
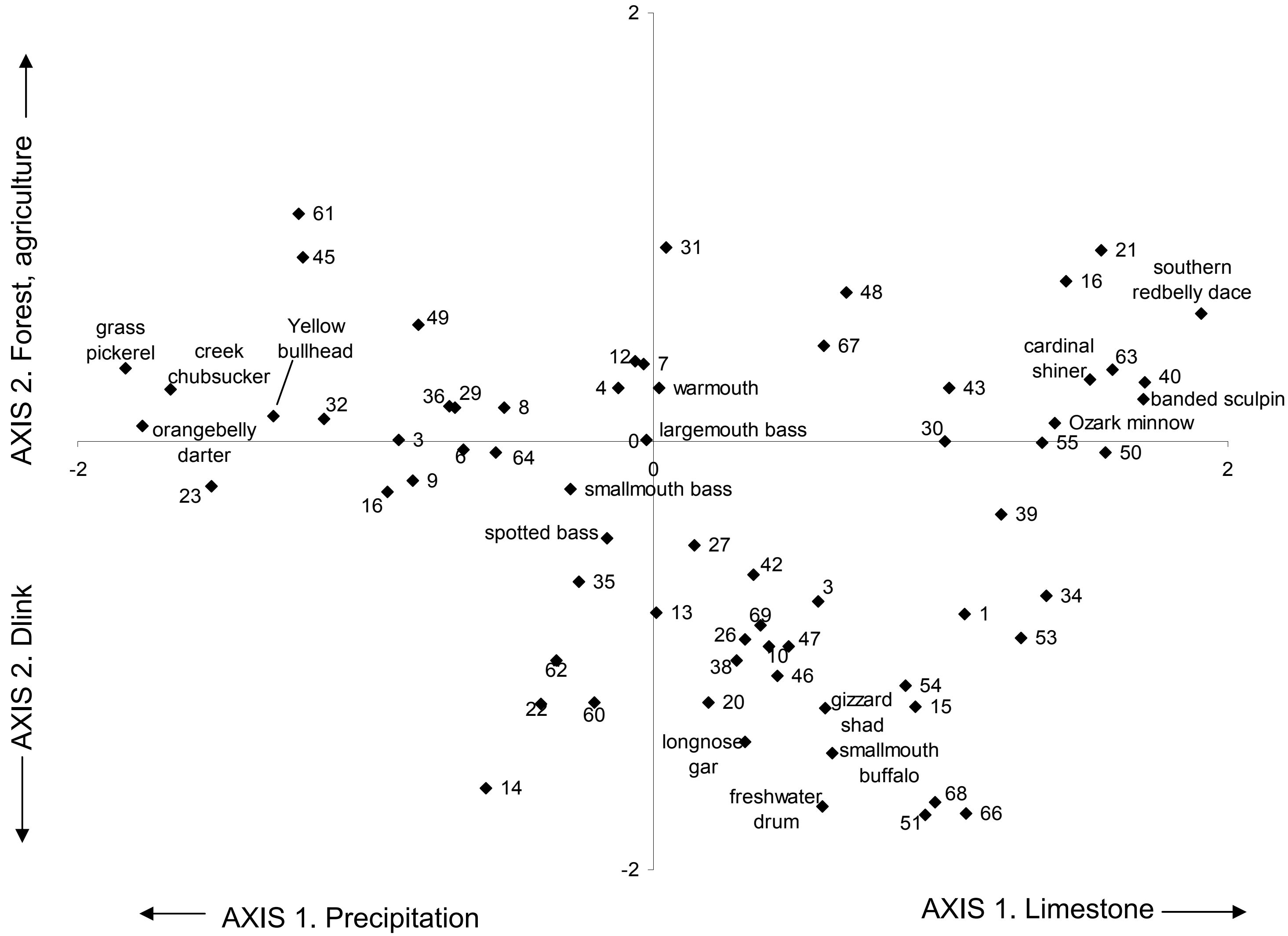


Figure 5. Detrended canonical correspondence analysis of fish species collected in eastern Oklahoma streams. See Table 7 for numbers that corresponds with fish species.



Appendix A. Cluster Analysis results by stream group.

Table 1. Clusters above the four stream groups identified.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
1	CL3 CL2	0.1251	0	47.3	
2	CL6 CL4	0.123	0.125	55.9	
3	CL5 CL7	0.0588	0.248	28.9	

Table 2.Cluster analysis results pertaining to the prairie stream group.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
7	CL15 CL12	0.0211	0.389	13.0	
12	CL14 CL34	0.0105	0.469	4.9	
14	CL60 CL26	0.0089	0.489	4.7	
15	CL45 CL23	0.0079	0.498	7.0	
23	CL35 CL36	0.006	0.551	5.6	
26	CL43 CL63	0.005	0.569	2.3	
34	CL136 CL114	0.0043	0.607	2.9	
35	CL70 CL69	0.0043	0.611	3.7	
36	CL105 CL115	0.0042	0.616	6.3	
43	CL61 CL58	0.0036	0.643	1.7	
45	CL68 CL103	0.0034	0.65	3.7	
58	CL90 SpringR3	0.003	0.691	1.7	
61	CL94 CL91	0.0029	0.7	1.5	
63	CL101 Poteau2	0.0028	0.706	1.9	
68	CL134 CL175	0.0026	0.719	3.2	
60	CL106 CL77	0.0029	0.697	2.4	
69	CL173 CL93	0.0026	0.722	1.6	
70	CL174 CL74	0.0026	0.724	2.9	
74	CL117 CL133	0.0025	0.735	2.3	
77	CL119 CL186	0.0024	0.742	2.5	
90	CL137 Kiami5	0.0021	0.772	1.4	
91	Gaines CL130	0.0021	0.774	1.4	T
93	LewisSl SpringR4	0.002	0.778	.	
94	BlkFrk1 MtFork4	0.002	0.78	.	T
101	ElkCr CL125	0.002	0.794	1.6	
103	CL141 CL190	0.0019	0.798	2.8	
105	CL187 CL146	0.0019	0.802	4.2	
106	CL200 VianCr	0.0019	0.804	1.8	
114	CL167 Turkey1	0.0017	0.818	1.5	
115	CL179 CL170	0.0017	0.82	1.8	T
117	CL209 CL199	0.0017	0.824	2.0	
119	CL144 CL191	0.0017	0.827	1.9	T
125	Illin16 CL220	0.0016	0.837	1.9	T
130	Illin5 Mustan1	0.0015	0.845	.	T
133	CL248 CL193	0.0015	0.85	1.8	T
134	BallCr2 Illin26	0.0015	0.851	.	T
136	FtGibson Illin18	0.0015	0.854	.	T
137	Glover4 Glover5	0.0015	0.856	.	T
141	CL188 CL217	0.0014	0.862	2.7	
144	CL302 CL216	0.0014	0.866	2.4	T
146	CL256 CL239	0.0014	0.869	2.8	
167	MudCr1 Pine2	0.0012	0.895	.	T
170	CL215 lillee4	0.0012	0.899	1.4	T
173	Hudson1 Hudson2	0.0012	0.903	.	T
174	CL285 CL241	0.0012	0.904	4.3	
175	CL203 CL226	0.0011	0.905	1.7	

Table 2 Continued.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
179	CL247 Greenlf1	0.0011	0.909	1.7	T
186	Brazil1 CL270	0.0011	0.917	2.1	T
187	CL235 CL283	0.0011	0.918	4.2	T
188	CL282 CL249	0.001	0.919	2.8	
190	Mustan2 Spavin3	0.001	0.921	.	
191	Brazil2 Norwd1	0.001	0.922	.	T
193	lilsall2 McKinn	0.001	0.924	.	T
199	Crook1 ElmCr	0.001	0.93	.	T
200	CL201 Bushy2	0.001	0.931	1.0	T
201	BigSkin2 BigSkin3	0.001	0.932	.	T
203	CL213 Walltr1	0.001	0.934	1.6	
209	BigSkin1 CL250	0.0009	0.94	1.3	T
213	CL271 CL265	0.0008	0.943	1.7	T
215	lillee2 Sallis5	0.0008	0.945	.	T
216	Cache1 OwlCr1	0.0008	0.946	.	T
217	lillee1 Negro2	0.0008	0.947	.	T
220	lilsall1 lilsall3	0.0008	0.949	.	T
226	CL299 Talequ2	0.0008	0.954	2.3	T
235	CL307 CL293	0.0007	0.961	3.3	T
239	Saline2 Sycam3	0.0007	0.964	.	T
241	littler11 MudCr2	0.0007	0.965	.	T
247	Buffalo1 Cucum1	0.0007	0.969	.	T
248	Cache2 Cache3	0.0007	0.97	.	T
249	CL289 Spring9	0.0007	0.971	3.0	T
250	Illin19 Norwd2	0.0007	0.971	.	T
256	CL273 Lukfata2	0.0006	0.975	1.8	T
265	Spring3 Walltr2	0.0005	0.98	.	T
270	lilskin1 lilskin2	0.0005	0.982	.	T
271	FlintBr lilfive	0.0005	0.983	.	T
273	CL321 Illin15	0.0005	0.984	3.0	T
282	BallCr5 Baron2	0.0005	0.988	.	T
283	CL306 CL324	0.0004	0.989	6.0	T
285	CL308 CL329	0.0004	0.99	6.0	T
289	CL318 CL319	0.0003	0.991	2.0	T
293	CL297 Illin1	0.0003	0.993	1.0	T
297	Beech2 CloudTr	0.0003	0.994	.	T
298	Snake3 TatePar	0.0003	0.994	.	T
299	FlintTr2 Peach3	0.0003	0.995	.	T
302	BigSkin4 Brushy1	0.0003	0.996	.	T
306	Drycr1 CL326	0.0002	0.997	.	
307	CL327 Snake2	0.0002	0.997	.	T
308	CL331 Kirk1	0.0002	0.997	.	T
318	FallBr Spring6	0.0002	0.999	.	T
319	Peach5 Spring5	0.0002	0.999	.	T
321	Bidding Greenlf2	0.0002	1	.	T
324	Spring2 Spring8	0	1	.	T

Table 2 Continued.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
326	Spring1 Spring11	0	1	.	T
327	BallTrib2 Scraper	0	1	.	T
329	Crutch Negro1	0	1	.	T
331	BallTrib1 LuckCr	0	1	.	T

Table 3. Cluster analysis results pertaining to the Ouachita stream group

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
6	CL8 CL17	0.023	0.366	14.9	
8	CL19 CL21	0.0182	0.41	14.9	
17	CL28 CL27	0.007	0.513	3.9	
19	CL25 CL100	0.0064	0.526	6.2	
21	CL41 CL96	0.0061	0.539	4.4	
25	CL33 CL40	0.0058	0.563	6.0	
27	CL65 CL48	0.005	0.574	3.3	
28	CL52 CL49	0.0048	0.579	3.2	
33	CL50 CL95	0.0043	0.603	4.7	
40	CL44 CL71	0.0038	0.632	4.7	
41	CL72 CL108	0.0036	0.636	3.2	
44	CL82 CL189	0.0035	0.646	6.0	
52	CL78 CL230	0.0031	0.673	2.5	
72	CL124 CL157	0.0026	0.73	2.8	
48	CL176 CL126	0.0033	0.66	2.8	
49	CL81 CL211	0.0032	0.663	2.4	
50	CL76 CL116	0.0031	0.666	3.9	
65	BuckCr CL185	0.0027	0.711	3.5	
71	CL161 CL128	0.0026	0.727	3.4	
76	CL111 CL104	0.0025	0.74	3.1	
78	CL102 CL97	0.0024	0.745	1.8	
81	CL129 CL158	0.0023	0.752	1.9	
82	CL181 CL210	0.0023	0.754	5.6	
95	CL168 CL243	0.002	0.782	2.3	T
96	CL153 Lukfata4	0.002	0.784	1.5	T
97	CL131 Lukfata3	0.002	0.786	2.0	T
100	CL132 CL204	0.002	0.792	2.2	
102	CL279 CL150	0.0019	0.796	2.1	T
104	CL140 CL163	0.0019	0.8	2.0	
108	CL156 littler12	0.0019	0.807	1.9	T
111	CL278 CL145	0.0018	0.813	3.8	
116	CL182 CL252	0.0017	0.822	3.3	T
124	CL169 CL206	0.0017	0.836	2.3	T
126	CL147 Wheel	0.0016	0.839	1.2	
128	Cripple CL202	0.0015	0.842	2.2	
129	CL162 Rock3	0.0015	0.844	1.3	
131	CL275 longtown	0.0015	0.847	3.0	T
132	CL269 lilturk	0.0015	0.848	3.0	T
140	CL219 CL183	0.0015	0.86	2.0	T
145	CL258 CL234	0.0014	0.867	3.3	
147	littler14 Stevens	0.0013	0.87	.	T

Table 3 continued.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
150	Holly1 SaltCr	0.0013	0.874	.	T
153	littler10 littler9	0.0013	0.878	.	T
156	Kiami3 CL207	0.0013	0.882	1.6	
157	CL276 Glover7	0.0013	0.883	2.6	T
158	CL194 Yashu3	0.0012	0.885	1.2	
161	CL231 CL236	0.0012	0.888	2.3	
162	Cypress2 Yanube2	0.0012	0.89	.	
163	Glover2 Sixmi	0.0012	0.891	.	T
168	CL224 Pine1	0.0012	0.897	1.4	T
169	CL314 MtFork3	0.0012	0.898	7.0	T
176	CL237 SandSp	0.0011	0.906	1.7	
181	CL233 CL286	0.0011	0.912	3.3	
182	CL294 CL257	0.0011	0.913	3.1	
183	CL263 Wfork2	0.0011	0.914	2.1	
185	Crook2 CL268	0.0011	0.916	2.1	T
189	Gibbs CL225	0.001	0.92	1.6	
194	Horseh Lukfata1	0.001	0.925	.	T
202	CL254 lilSilver	0.001	0.933	1.8	
204	CL208 Cloudy5	0.001	0.935	1.2	
206	CL242 littler7	0.0009	0.937	1.3	T
207	CL244 littler6	0.0009	0.938	1.3	T
208	Cloudy4 CL238	0.0009	0.939	1.3	T
210	CL228 CL291	0.0008	0.941	2.9	
211	Yanube1 Yashu1	0.0008	0.942	.	
219	CL262 littler5	0.0008	0.948	1.7	T
224	Cloudy3 CowCr	0.0008	0.953	.	T
225	CL253 Yashu2	0.0008	0.953	1.5	
228	Cedar2 CL288	0.0008	0.956	2.3	T
230	Cane CL292	0.0008	0.957	2.3	T
231	CL277 Rock5	0.0008	0.958	2.3	
233	CL272 CL296	0.0007	0.96	2.2	T
234	Cloudy2 CL305	0.0007	0.96	3.3	
236	LickCr Willis	0.0007	0.962	.	
237	Cypress1 WhitOk	0.0007	0.962	.	T
238	Jack1 Turkey2	0.0007	0.963	.	T
242	Buffalo3 MtFork5	0.0007	0.966	.	T
243	Lukfata5 Lusukla	0.0007	0.966	.	T
244	littler2 littler8	0.0007	0.967	.	T
252	CL274 Wfork4	0.0006	0.973	1.2	
253	Midcar CL266	0.0006	0.973	1.2	T
254	Honob4 CL267	0.0006	0.974	1.2	T
257	CL295 CL310	0.0006	0.976	2.3	T
258	CL301 Wfork3	0.0006	0.976	1.7	

Table 3. Cont.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
262	BlkFrk3 Watson	0.0005	0.978	.	
263	EastFk5 Wfork1	0.0005	0.979	.	T
266	MtFork2 Uphill	0.0005	0.98	.	T
267	Hurric1 Silver	0.0005	0.981	.	T
268	NCaney1 Scaney	0.0005	0.981	.	T
269	BlkFrk2 littler4	0.0005	0.982	.	T
272	BigEag1 CL311	0.0005	0.983	3.0	T
274	Eboktuk Honob2	0.0005	0.984	.	T
275	Caney Holly2	0.0005	0.985	.	T
276	Glover1 Glover6	0.0005	0.985	.	T
277	Cloudy1 CL315	0.0005	0.986	3.0	T
278	CL280 Cucum3	0.0005	0.986	1.8	T
279	Boktuk Coon1	0.0005	0.987	.	T
280	CL317 CL322	0.0005	0.987	3.0	T
286	CL312 CL328	0.0004	0.99	5.0	T
288	Pero1 Rock2	0.0003	0.991	.	T
291	CL330 CL323	0.0003	0.992	.	T
292	Copper LostSpr	0.0003	0.992	.	T
294	BigEag2 Honob1	0.0003	0.993	.	T
295	BigEag3 EastFk3	0.0003	0.993	.	T
296	Cucum2 EastFk2	0.0003	0.994	.	T
301	BgHud Hurric2	0.0003	0.995	.	T
305	CL316 EastFk4	0.0003	0.997	1.7	T
310	Honob3 Rock4	0.0002	0.998	.	T
311	LilCow Pine4	0.0002	0.998	.	T
312	Carpen Pine3	0.0002	0.998	.	T
314	Buffalo2 littler1	0.0002	0.998	.	T
315	Drycr2 LilDry	0.0002	0.999	.	T
316	EastCr EastFk1	0.0002	0.999	.	T
317	Beech1 Coon2	0.0002	0.999	.	T
322	Carter Cedar1	0.0002	1	.	T
323	NCart1 Wfork5	0	1	.	
328	littler3 Rock1	0	1	.	T
330	LilEgl Mine	0	1	.	T

Table 4. Cluster analysis results pertaining to the Ozark stream group.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
5	CL11 CL9	0.0278	0.338	14.2	
9	CL20 CL22	0.0155	0.428	6.7	
11	CL24 CL29	0.0106	0.458	8.2	
20	CL38 CL64	0.0064	0.533	4.1	
22	CL30 CL51	0.006	0.545	2.2	
24	CL37 CL84	0.006	0.557	4.0	
29	CL99 CL89	0.0048	0.584	6.2	
30	CL32 Sycam1	0.0047	0.589	1.6	
32	CL42 CL54	0.0045	0.598	1.6	
38	CL57 CL139	0.0039	0.624	2.8	
42	CL67 Baron5	0.0036	0.639	1.3	
51	CL109 CL135	0.0031	0.67	2.1	
54	CL62 CL87	0.0031	0.679	1.3	T
55	CL148 CL86	0.0031	0.682	3.2	
57	CL85 CL118	0.003	0.688	2.4	
62	CL73 CL88	0.0029	0.703	1.2	
37	CL47 CL55	0.0041	0.62	3.0	
47	CL59 CL160	0.0034	0.657	2.5	
59	CL120 CL155	0.0029	0.694	2.2	
64	CL83 CL164	0.0028	0.708	2.2	
67	BallCr4 Illin10	0.0027	0.717	.	T
73	Baron7 Honey3	0.0025	0.732	.	
83	CL177 CL166	0.0023	0.756	2.3	
84	CL113 Honey2	0.0023	0.759	1.9	
85	CL184 CL165	0.0022	0.761	2.4	
86	CL159 TullyH	0.0022	0.763	3.3	
87	ParkHill Talequ1	0.0022	0.765	.	T
88	forteen2 Honey1	0.0022	0.767	.	T
89	CL112 CL180	0.0021	0.77	2.8	
99	CL232 CL251	0.002	0.79	5.0	
109	Baron1 Illin9	0.0019	0.809	.	T
112	CL149 CL143	0.0018	0.815	2.3	
113	CL127 CL223	0.0018	0.817	1.7	
118	CL154 CL142	0.0017	0.825	1.5	
120	CL198 CL151	0.0017	0.829	1.4	
127	CL178 Sycam2	0.0016	0.84	1.8	T
135	CL171 Illin25	0.0015	0.853	1.3	T
139	CL197 Flint4	0.0015	0.859	1.4	T
142	CL196 CL222	0.0014	0.863	1.5	
143	Clear2 CL218	0.0014	0.864	2.1	T
148	Brush1 Spavin2	0.0013	0.871	.	T

Table 4 continued.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
149	CL192 CL259	0.0013	0.873	2.4	T
151	Sager1 Sager2	0.0013	0.875	.	T
154	Baron4 Flint2	0.0013	0.879	.	T
155	Baron10 CameSpr	0.0013	0.881	.	T
159	CL229 CL227	0.0012	0.886	2.2	T
160	CL205 CL214	0.0012	0.887	1.5	
164	Sallis3 Sallis6	0.0012	0.892	.	T
165	Baron3 Sallis4	0.0012	0.893	.	T
166	Sallis1 Sallis2	0.0012	0.894	.	T
171	Illin24 Illin30	0.0012	0.9	.	T
177	CL246 Sallis7	0.0011	0.907	1.7	T
178	Fivemile CL240	0.0011	0.908	1.7	T
180	CL255 CL212	0.0011	0.911	2.7	
184	CL281 Spavin4	0.0011	0.915	2.1	T
192	CL300 Noname	0.001	0.923	3.0	T
196	Illin20 Illin27	0.001	0.927	.	T
197	Baron8 Evans2	0.001	0.928	.	T
198	BallCr1 Evans1	0.001	0.929	.	T
205	CL245 Spring10	0.0009	0.936	1.3	
212	lillee3 Talequ3	0.0008	0.942	.	T
214	Roark1 Spavin1	0.0008	0.944	.	T
218	forteen5 CL264	0.0008	0.947	1.7	T
222	Illin21 Illin22	0.0008	0.951	.	T
223	Flint3 Flint5	0.0008	0.952	.	T
227	CL260 Roark2	0.0008	0.955	1.8	T
229	Crazy CL290	0.0008	0.957	2.3	T
232	CL261 Spring7	0.0007	0.959	2.2	
240	LostCr Snake1	0.0007	0.964	.	T
245	forteen3 forteen6	0.0007	0.968	.	T
246	forteen1 forteen4	0.0007	0.969	.	T
251	CL284 Walltr3	0.0006	0.972	2.9	
255	CL304 CL313	0.0006	0.974	2.9	
259	CL298 Tyner3	0.0006	0.977	1.7	T
260	CL287 Peach1	0.0006	0.977	1.7	T
261	CL303 Summer2	0.0006	0.978	2.5	T
264	LostCrTr Warren	0.0005	0.979	.	T
281	BallCr3 Baron6	0.0005	0.988	.	T
284	Baron9 CL325	0.0004	0.989	.	T
287	Luna Tyner2	0.0003	0.991	.	
290	England Peach4	0.0003	0.992	.	T
300	BeatyCr Peach2	0.0003	0.995	.	T
303	CL320 Whitwa	0.0003	0.996	1.7	
304	CL309 Tyner1	0.0003	0.996	1.7	T
309	CaveSpr Summer1	0.0002	0.998	.	T
313	Clear1 Mason1	0.0002	0.998	.	T
320	Baron11 Saline1	0.0002	0.999	.	T
325	FlintTr1 Spring4	0	1	.	T

Table 5 Cluster analysis results pertaining to low gradient streams.

Cluster number	Clusters joined	SPRSQ	RSQ	PST2	Tie
4	CL13 CL10	0.0314	0.307	9.7	
10	CL31 CL18	0.0146	0.444	5.4	
13	CL66 CL16	0.0097	0.479	4.3	
16	CL332 CL39	0.007	0.506	3.0	
18	CL53 CL75	0.0065	0.52	3.0	
31	CL80 CL56	0.0046	0.594	2.2	
46	Illin3 Illin6	0.0034	0.653	.	
53	Illin14 CL107	0.0031	0.676	1.7	
39	CL98 CL46	0.0039	0.628	1.4	
56	CL79 CL121	0.003	0.685	1.6	
66	CL172 CL92	0.0027	0.714	1.9	
75	CL152 Poteau3	0.0025	0.737	1.8	
79	CL123 Poteau1	0.0024	0.747	1.4	
80	CL122 Kiami2	0.0024	0.749	1.4	T
92	CL110 CL138	0.0021	0.776	1.6	T
98	Illin2 Illin29	0.002	0.788	.	T
107	SpringR1 SpringR2	0.0019	0.806	.	T
110	Illin13 CL221	0.0019	0.811	2.2	T
121	littler13 MtFork6	0.0017	0.831	.	T
122	Glover3 MtFork1	0.0017	0.832	.	T
123	Kiami1 Kiami4	0.0017	0.834	.	T
138	CL195 Illin7	0.0015	0.857	1.4	
152	Neosho1 Neosho2	0.0013	0.877	.	T
172	Flint1 Illin28	0.0012	0.901	.	T
195	Illin23 Illin8	0.001	0.926	.	T
221	Illin17 Illin4	0.0008	0.95	.	T
332	Illin11 Illin12	0	1	.	T

VITA

Ellen C. Tejan

Candidate for the Degree of

Master of Science

Thesis: LANDSCAPE SCALE INFLUENCES ON STREAM FISH ASSEMBLAGES IN INTERIOR HIGHLAND STREAMS IN EASTERN OKLAHOMA

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Title of Study: LANDSCAPE-SCALE INFLUENCES ON STREAM FISH ASSEMBLAGES IN EASTERN OKLAHOMA

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Scope and Method of Study: Ecoregions are commonly used as a starting point for regional management planning and conservation applications. The objective of this study was to relate watershed characteristics to stream fish assemblages among aquatic ecoregions and stream types in eastern Oklahoma. We compiled fish collection data from three studies in eastern Oklahoma, and filled data gaps by seining streams that were not represented in these collections. Watershed and stream characteristics were compiled and summarized using a GIS. Differences in stream and watershed characteristics and fish assemblage parameters among ecoregions were analyzed with analysis of variance and least significant difference multiple comparison test. Multivariate techniques were used to identify stream groups and relationships between species assemblages and watershed characteristics.

Findings and Conclusions: The Ouachita Mountains had the highest mean annual precipitation and was dominated by forest. Shale dominated, they also had the greatest topographic relief and valley slopes. The Arkansas Valley and Central Irregular Plains were predominantly low relief, low slope sandstone basins dominated by prairie and agriculture. Limestone was dominant in the Ozark Highlands with the Boston Mountains containing limestone and shale. These ecoregions also had high topographic relief, woodlands and prairie. We identified four clusters: Ozark streams, plains streams, Ouachita streams, and low gradient streams. Only the Ouachita group coincided with aquatic ecoregional boundaries. This group organized along gradients of geology and land use. The Ozark streams, low gradient streams and plains streams, however, grouped together regardless of the ecoregion in which they occurred. Ecoregions, while having some relationship to stream fish assemblage structure, may serve as the best template for regional fish management. To adequately capture fish assemblage patterns and issues, one must delineate management regions specific to streams, with a clear understanding of landscape patterns, stream channel conditions, habitat features.

ADVISOR'S APPROVAL: ____William L. Fisher__________________________