Physicochemical Factors Affecting the Abundance and Species Richness of Fishes in the Cimarron River

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We analyzed fish assemblage parameters (species richness, density, and biomass) and physicochemical conditions in the Cimarron River using correlation and multiple regression techniques to define factors influencing the abundance and species richness of fishes at seven sites in four ecoregions along 811 kilometers of the river. The data were obtained by the Oklahoma State Department of Health during 1976-1986. Significant differences in dissolved oxygen, temperature, turbidity, conductivity, and flow rate were observed among sites, reflecting longitudinal changes in physiography, land use, and tributary influence. Fish assemblage parameters and physicochemical variables were more frequently correlated at upstream sites than at downstream sites. At upstream sites, fish species richness, density, and biomass were positively correlated with typical low-flow conditions. These parameters increased when water velocity, average depth, flow rate, and turbidity decreased. Multiple regression analyses indicated a trend to higher r^2 values at upstream sites for all three parameters when the variation in these parameters was explained by variation in physicochemical factors. The more harsh and extreme environmental conditions at upstream sites (e.g., in isolated pools during late summer, with little or no shading and non-point-source pollution) and less potential biotic interactions may explain the more profound influence of a few variables on fish abundance and diversity in the Cimarron River.

INTRODUCTION

The factors influencing the abundance and diversity of temperate riverine fishes can be divided into physical, chemical, biological and zoogeographic factors (1). The influence of habitat or water quality variables on fishes have been observed during short, intensive studies or other studies limited to short river reaches (e.g., 2-4). The associations between fish community parameters and habitat/water quality variables have been studied along a broad longitudinal axis (5). Because such parameters vary owing to a complex array of stochastic and/or deterministic effects (6), long-term studies are ideal because they incorporate both annual and seasonal variation. Studies of fishes along a broad longitudinal gradient allow elucidation of factors affecting fish abundance and diversity in discrete geographic areas (e.g., tributary influence, point and non-point pollution effects, stream size).

The Cimarron River in Oklahoma is a large, undammed river flowing through four major ecoregions: the Southwestern Tablelands, Western High Plains, Central Great Plains, and Central Oklahoma/Texas Plains (7). The Cimarron, like many other Central Plains rivers, has high watershed erosion, high concentrations of dissolved and suspended solids, shifting sand substrate, and low faunal diversity relative to eastern Mississippi drainages (8-10).

Since 1976, the Oklahoma State Department of Health (OSDH) has conducted standardized fish sampling at several Cimarron River sites for the Statewide Biotrend Monitoring Program. Pigg (10) determined fish abundance, species richness, species diversity, and species distribution at ten sites using data from 1976-1986. This paper attempts to define what factors, if any, influence the abundance and species richness of Cimarron River fishes along a geographical gradient, using statistical associations between fish assemblage parameters and physicochemical variables. We sought to answer the following questions 1) what single variables are associated with fish assemblage parameters, and do these vary longitudinally? and 2) what combinations of variables explain variation in fish assemblage parameters, and do these vary longitudinally?

METHODS

Fish collection, water quality, and physical habitat data from seven Cimarron River sampling sites were from OSDH records. Data from Cimarron River Sites 1-4, 7, 8, and 10 were used corresponding to collections from 1976 through 1986 (10).

The following variables were measured: species richness (number of species collected), total fish density (number of fish/m^2), total fish biomass (g/m^2), dissolved oxygen (mg/L), water temperature (°C), specific conductance (millisiemens, mS), turbidity (NTU), mean depth (m), percent pool habitat, water velocity (m/s), and flow (m^3/s). Methods for collection and measurement of physicochemical variables were previously published (10). Flow rate data not obtained on collection dates were from US Geological Survey records.

Site-specific analyses of these data included descriptive statistics (median, minimum, maximum, and coefficient of variation) and Spearman rank correlation (11). A non-parametric analysis of variance test (Kruskal-Wallis test) was performed on physicochemical variables to test for significant differences among all sites. Multiple regression analysis using the SAS RSQUARE procedure (11) was performed to determine the percent variation in dependent variables (fish parameters) that could be explained by variation in independent variables (listed above). The multiple regression analysis was limited to one, two, three, and four-variable models because of time constraints. Significance of regression models was obtained using the SAS STEPWISE MAXR procedure (11).

RESULTS

Water velocity, mean depth, and percent pool showed no significant differences among all sites (Kruskal-Wallis test: $P > 0.05$). Significant differences among all sites were indicated for dissolved oxygen ($P < 0.05$), temperature ($P < 0.01$), turbidity ($P < 0.01$), conductivity ($P < 0.0001$), and flow rate ($P < 0.0001$) (Kruskal-Wallis test). For most parameters the differences among sites were related to longitudinal position; water temperature, conductivity, and flow rate showed apparent longitudinal trends or distinct regional peaks (Table 1).

Median water temperature values generally increased downstream. The relatively high median value observed at Site 1 reflects typical river conditions in the westernmost section. The site frequently has isolated pools having little or no shading. Median conductivity values generally increased downstream, reflecting both local geological characteristics and the likely greater influence of tributaries with elevated chloride levels. Median conductivity levels were highest at Sites 4 and 7 (Table 1). Tributaries having extremely high chloride concentrations enter the Cimarron River upstream of Site 4 (unnamed tributary) and Site 7 (Elm, Buffalo, and Salt Creeks).

As expected, median flow rate increased downstream (Table 1). Variability of flow (as estimated by coefficient of variation values) was lowest at the three downstream sites and highest at Sites 1-4. Species richness generally increased downstream, as previously reported (9). With the exception of flow rate, no site or cluster of sites had consistently greater variability in physicochemical variables.

Longitudinal trends in median dissolved oxygen and turbidity were not apparent, and no site had consistently limiting oxygen conditions. The lowest concentration of dissolved oxygen measured at the five upstream sites ranged from 5.6 to 6.3 mg/L (Table 1). Though minimum dissolved oxygen concentrations at sites 8 and 10 were below 4.0 mg/L (Table 1), all other measurements between 1976 and 1986 exceeded 5.0 mg/L (OSDH).

Correlations between physicochemical variables and fish community parameters were evident at all sites but the number and strength of correlations were skewed toward distinct clusters of sites (Table 2). These data show that the most apparent trend is increased frequency of significant associations at upstream sites. The strength (i.e., significance level) of associations was greater at upstream sites also. Sites 1 and 2 are in Cimarron River headwaters whereas Site 4, though having relatively higher average flow rate compared to these sites, still consisted of small isolated pools during late summer. There were fewer significant associations at downstream Sites 7, 8 and 10. Of these sites, Site 10 had the most significant correlations.

At upstream Sites 1, 2, and 4, there was a positive relationship between community parameters and low flow conditions (species richness, density, and biomass increased when percent pool and conductivity decreased and,

TABLE 1. Geographical, physicochemical, and species richness parameters of fish collection sites in the Cimarron River, 1976–1986.

	Cimarron River sampling site						
Parameter^{a}	1	2	3	4	7	8	10
Distance^{b}, km	950	776	547	474	258	194	139
Drainage area, km^2	2,876	4,885	26,250	31,023	40,854	43,924	46,420
Dissolved O_2, mg/L	11.1(23) [5.8–13.8]	7.9(22) [5.6–11.8]	8.4(20) [5.6–9.9]	8.5(14) [6.0–11.2]	8.7(23) [6.3–14.0]	7.8(28) [3.5–13.4]	9.7(27) [3.5–13.9]
Temperature, °C	25.0(30) [13.0–35.1]	21.4(28) [11.0–30.2]	20.8(26) [10.2–26.0]	22.8(28) [5.5–32.5]	27.2(25) [10.0–32.0]	27.0(17) [14.6–33.0]	25.0(20) [14.5–32.0]
Turbidity, NTU	54(89) [3–175]	38(174) [1.1–1,000]	21(179) [4–525]	4(201) [1–220]	34(116) [4–220]	61(106) [2.5–310]	25(94) [1–180]
Conductivity, mS	1.661(77) [0.089–5.51]	1.613(65) [0.501–4.66]	3.272(28) [1.81–4.66]	9.782(96) [2.38–57.7]	8.080(52) [0.800–17.3]	5.311(46) [2.95–12.5]	5.240(50) [0.740–13.2]
Flow rate, m^3/s	0.0(147) [0.0–0.18]	0.02(335) [0.0–19.47]	0.27(125) [0.10–3.06]	0.41(258) [0.0–94.52]	7.78(107) [0.79–67.92]	13.36(113) [4.25–99.05]	10.56(99) [1.70–75.84]
Species richness	8(17) [5–10]	6(21) [5–10]	8(18) [6–11]	5(57) [1–13]	11(28) [6–18]	12(30) [8–22]	14(27) [8–21]

^{a} Table format for physicochemical and species richness parameters: median(coefficient of variation); [minimum–maximum values].
^{b} River distance from mouth

TABLE 2. Spearman rank correlation results and corresponding significance levels for associations between fish community parameters and physicochemical variables at Cimarron River sites, 1976–1986.

Fish		Cimarron River site (upstream to downstream)					
parameter	Variable	1	2	4	7	8	10
Species richness	D. oxygen			−0.33^{a}			
	Temperature			0.30^{a}			
	Conductivity	0.44^{a}		−0.58^{c}			
	Flow rate			0.43^{b}	0.41^{a}		
	% pool		0.50^{a}				
	Velocity						0.31^{a}
	Mean depth	−0.62^{c}	−0.55^{b}		0.51^{b}		
Fish density	D. oxygen	0.45^{a}		0.34^{a}			0.35^{a}
	Temperature		0.72^{c}				
	Conductivity	0.51^{b}		0.38^{a}			−0.42^{a}
	Turbidity			−0.38^{a}			−0.39^{a}
	Flow rate		−0.82^{d}	−0.56^{d}			−0.53^{c}
	% pool	0.43^{a}	0.74^{c}		−0.42^{a}		
	Velocity	−0.47^{a}	−0.93^{d}			−0.48^{b}	
	Mean depth	−0.72^{c}		−0.32^{a}			
Fish biomass	D. oxygen	0.60^{b}		0.35^{a}		0.39^{a}	
	Temperature	0.45^{a}	0.49^{a}				
	Conductivity	0.83^{d}					
	Turbidity		−0.55^{a}	−0.60^{c}			
	Flow rate			−0.61^{d}			
	Velocity	−0.56^{b}	−0.58^{b}			−0.37^{a}	
	Mean depth	−0.68^{c}		−0.51^{c}			−0.41^{b}

^{a,b,c,d} Significance levels: ^{a} $P<0.1$; ^{b} $P<0.05$; ^{c} $P<0.01$; ^{d} $P<0.001$.

alternatively, when water velocity, average depth, flow rate, and turbidity decreased). This relationship was observed at Site 10 only for fish density. An exception to the trend was Site 4, where species richness increased with increasing flow rate and decreasing conductivity. This is understandable since Site 4 was the most saline one (Table 1), and thus high flow events probably allow nonlimiting conditions for species intolerant of high salinity.

Dissolved oxygen and water temperature

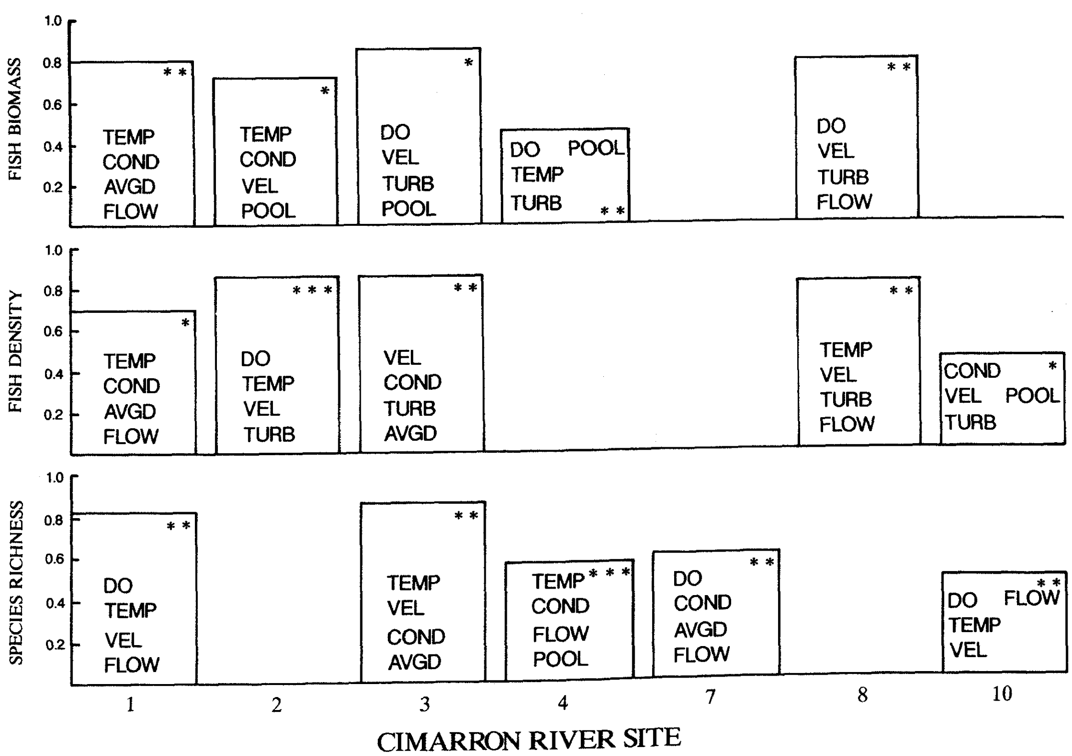
also correlated with increasing fish density and biomass. Because increased water temperature is associated with low-flow conditions, this result is not surprising. Productive, diverse fish communities are generally associated with high oxygen levels.

Multiple regression analyses indicated that a combination of four physicochemical variables explained a high percent of variation in fish community parameters at some but not all sites (Figure 1). Multiple regression data clearly show higher r^2 values for all three community parameters at headwater sites (sites 1, 2, and 3). Thus, the variation in physicochemical variables accounted for a much higher percentage of fish parameter variation at Cimarron River headwater sites. Using a four-variable model, observed r^2 values for species richness, density and biomass exceeded 0.70 at sites 1-3 except for species richness at Site 2 ($r^2 = 0.48$). The only downstream site with r^2 values greater than 0.50 for all three parameters (using a four-variable model) was Site 8. At this site the r^2 values for species richness, density, and biomass were 0.62, 0.82, and 0.79, respectively. Turbidity and flow rate were two variables included in the highest predictive four-variable model for all three community parameters at Site 8.

At headwater Sites 1-3 the physicochemical variables included in most of the eight four-variable models (species richness at Site 2 deleted because $r^2 < 0.50$) were temperature (six of eight models), velocity (six of eight), conductivity (four of eight), and mean depth (four of eight). Temperature, velocity, and mean depth were included in five of the eight three-variable models at these sites also. These results suggest that temperature, velocity, conductivity, and mean depth had the greatest influence when all three community parameters are considered together.

On the basis of one-variable models alone, the variables with the highest r^2 values at Sites 1-3 were velocity ($r^2 = 0.64$: fish density at Site 2; $r^2 = 0.49$: species richness at Site 3), conductivity ($r^2 = 0.44$: fish biomass at Site 1), and percent pool ($r^2 = 0.42$: fish density at Site 3). One-variable models at further downstream sites generally had lower r^2 values; such values greater than 0.40 were observed only for flow rate ($r^2 = 0.41$: species richness at Site 7) and dissolved oxygen ($r^2 = 0.52$: fish biomass at Site 8).

Figure 1. Combinations of physicochemical variables accounting for variation in fish community parameters.



DISCUSSION

The Cimarron River undergoes considerable changes in land form and use, water quality, and fish community structure from source to mouth. Analyses of long-term data reported in this paper, however, indicate longitudinal differences in the magnitude of influence that physicochemical variables have on fish community parameters. Both correlation and multiple regression results describe this differential influence: at Cimarron River headwaters a few physicochemical variables explain a high percentage of variation in species richness, fish density, and fish biomass. Thus, relatively few variables have profound effects on fishes in these reaches. Conversely, in general a combination of up to four physicochemical variables explain a much lower proportion of variation in fish parameters at downstream sites. These results represent more or less average degrees of influence on fish community parameters, and thus temporal variation was not determined.

The results are not surprising in view of our current understanding of Central Plains rivers and intermittent reaches of these systems. Such reaches are characterized by relatively unstable physicochemical features that result in more marked perturbation effects (e.g., point and nonpoint pollution) (12). Stream flow is probably the most important physical variable affecting chemical characteristics and biological communities, and all biota must adapt to survive harsh conditions produced by desiccation or seasonal spates (9, 12). Headwaters of prairie streams are typically sunlit owing to a lack of forest canopy cover (e.g., Cimarron River Site 1), and thus temperatures may reach or exceed tolerance levels of aquatic biota (9).

Long-term fishery data for Cimarron River headwaters clearly indicate a fish assemblage adapted to intermittent prairie streams (9). Dominant species at headwater sites include stoneroller *(Campostoma anomalum)*, flathead chub *(Hybopsis gracilis)*, red shiner *(Notropis lutrensis)*, sand shiner *(Notropis stramineus)*, suckermouth minnow *(Phenacobius mirabilis)*, fathead minnow *(Pimephales promelas)*, plains killifish *(Fundulus zebrinus)*, and green sunfish *(Lepomis cyanellus)*. Most of these species are omnivorous feeders, being either 1) characteristic of plains fauna or 2) ubiquitous species having broad environmental requirements. An unusual fish assemblage is characteristic of saline western Oklahoma streams (13). The relatively few species that are successful in these reaches should exhibit morphological, behavioral, or physiological adaptations to such limiting conditions. Matthews (14) observed increased physiological tolerances in species typical of intermittent prairie streams as compared to cogeners representative of perennial, benign habitats.

We hypothesize that the observed greater influence of a few physicochemical variables at headwater sites reflects a more "simple" ecosystem at these sites in contrast to a more "complex" one at downstream sites. We use these terms to represent the sum of all abiotic and biotic factors that potentially affect the structure and function of fish communities. Species richness at Cimarron River headwaters is depauperate compared to downstream sites, a pattern similar to that in other prairie streams (9, 12). The paucity of species probably increases the magnitude of the effect of abiotic factors whereas the influence of biotic interactions is likely reduced. This hypothesis may explain observed r^2 values exceeding 0.80 for fish community parameters at headwater sites based on variation in four physicochemical variables.

Downstream sites have greater flow rates, more stable physicochemical features, and potentially greater influence from tributaries concerning biotic interactions. More species of fishes are present in middle and lower Cimarron River sites and thus biotic interactions are probably more important in regulating fish communities. We speculate that physicochemical variables are important influences on fish diversity and abundance in these reaches, but less limiting conditions probably make effects of single variables less apparent (Table 2).

Another factor that may influence observed differences in longitudinal trends is greater sampling efficiency at headwater sites. Sampling of fishes in isolated pools was undoubtedly more efficient than at sites where the stream was wide. Estimates of fish community parameters are probably more accurate at headwater sites and thus associations with physicochemical variables should be more pronounced. However, sampling methodology was very consistent at all Cimarron River sites and long-term data incorporate both annual and seasonal variability.

Physicochemical factors associated with fish community parameters in the Cimarron River showed no consistent longitudinal trends. That is, no factor or group of factors were geographically unique in explaining variation in fish parameters. Our analysis did not include statistical analysis of factors on a longitudinal axis *per se*, however. For example, species richness of fishes in the Cimarron River clearly increases with drainage area and flow rate (10) (Table 1). Several factors observed to influence Cimarron River fishes were also important in discriminating fish assemblages in Kansas streams (stream discharge, mean depth, water temperature, percent pool, and a measure of specific conductance) (15). Long-term monitoring of the Cimarron River clearly indicates how useful measurements of routine water quality and habitat variables are in defining specific factors affecting fish communities.

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