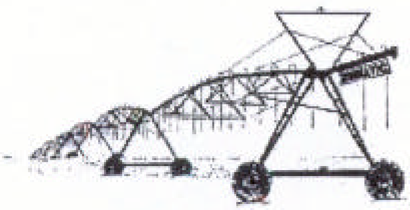
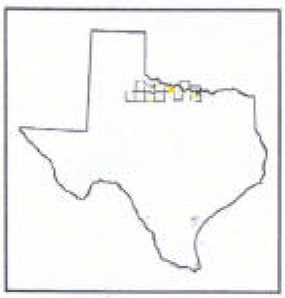
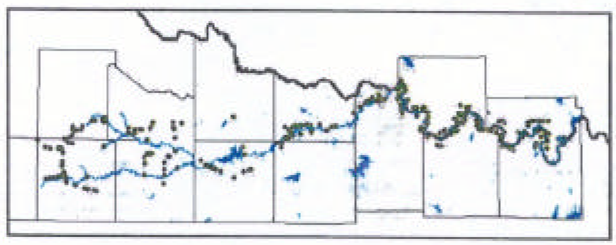


Analysis of the Wichita Portion of the Red River Chloride Control Project
September 15, 2000

Analysis of Fish Distribution in the Wichita River System and Red Tributaries





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Texas Agricultural Experiment Station
The Texas A&M University System

in cooperation with

US Army Corps of Engineers ®

Tulsa District

PROJECT

Analysis of the Wichita Portion of the Red River chloride control Project (RRCCP) and Implications to the Red River that Includes an Integrated effort of Economics, Hydrologic Simulation Models, Geographical Information Systems (GIS) and Environmental Factors

Report for

Analysis of Fish Distribution in the Wichita River System and Red River Tributaries from the Wichita River Confluence to Lake Texoma as Related to Environmental Variables in Summer 1998

with

Stochastic Models for Distribution of Two Salt-tolerant Species under Conditions of Estimated Land Use and Concentration of Total Dissolved Solids for Five Alternative Plans by U.S. Army corps of Engineers for Control of Saltwater Inflows to the Wichita River

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This is one of six reports that address the region, hydrologies, environment and economics. The Texas Agricultural Experiment Station research team was comprised of the following

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Table of Contents

List of Tables

List of Figures

Analysis Of Fish Distribution In The Wichita River System And Red River Tributaries From The Wichita River Confluence To Lake Texoma As Related To Environmental Variables In Summer 1998 With Stochastic Models For Distribution Of Two Salt-Tolerant Species Under Conditions Of Estimated Land Use And Concentration Of Total Dissolved Solids For Five Alternative Plans By US Army Corps Of Engineers For Control Of Saltwater Inflows To The Wichita River

Abstract

Fishes were collected in August 1998 from the main Wichita River and its tributaries and tributaries of the Red River from the Wichita River confluence to Lake Texoma, designated as Reaches 5, 6, 7, 9, 10, 11, and 12. These reaches could be potentially influenced by five alternative COE Project Plans to control saltwater inflows to the Wichita River (before project initiation, at present project level, and three possible project expansions). Fish densities were correlated to combinations of environmental variables measured at each site, as well as land use data from Geographic Information Systems databases, and water quality data output from models run under the five alternative COE Project Plans. Separate regression models were developed to analyze the relationship of density for each of two salt-tolerant species — Red River pupfish, *Cyprinodon rubrofluviatilis*, and plains killifish, *Fundulus zebrinus* — with respect to environmental variables. Combinations of environmental variables correlated with fish density differed for spatial regions upstream of Lakes Kemp and Diversion (Reaches 9-11), compared to those downstream (Reaches 5, 6, 7, and 12). The estimated values under alternative Project Plans for Total Dissolved Solids (TDS), Pasture/Hay Dry and Irrigated Crop land were used to estimate relative changes in density of each salt-tolerant species in each Reach, based on relationships developed from 1998 field data.

With the exception of the two target salt-tolerant species, differences among fish assemblages were strongly correlated with variation in environmental values at the scale of individual sites, whereas environmental variation and assemblage composition was relatively similar among whole reaches. Land use was most strongly correlated with fish distributions followed by instream water quality and physical habitat measurements (e.g., depth, velocity), and finally riparian variables (e.g., vegetation type). Four assemblage types were identified. Two types were dominated by a different salt-tolerant species. These two assemblage types rarely included species other than stress-tolerant species with generalist strategies of habitat and food use. The two salt-tolerant species and one introduced estuarine species—inland silversides (*Menidia beryllina*)—had peak occurrence at sites with higher values for salinity-related variables (conductivity, Chloride, and TDS), but low occurrence if these values were low, and especially where numbers of intolerant species were high.

For Reaches 6, 7, 9 and 12, stochastic models indicated that low-range density estimates (mean -1 standard deviation, and lower 5th % tile) for Red River pupfish dropped from pre-project conditions (Plan 1), to present project conditions (Plan 2), and further

declined under conditions of alternative expansion Plans 3-5. In Reach 11, estimates for Red River pupfish declined from Plan 1 to Plan 2. For plains killifish in Reaches 7, 9 and 12, stochastic models indicated low-range estimates dropped under Plans 3 and 5 below those for Plans 1 and 2. Estimates for other Reaches and under other Plans were above or similar to those for Plans 1 and 2. Overall, mean densities under Plans 2-5 were within 1 standard deviation of densities for Plan 1 in all cases except for Red River pupfish in Reaches 9-11, and for plains killifish in Reach 9 (where they were lower for both species). Mean densities under Plans 2-5 for all Reaches were between the 5th % tile and 95th % tile of Plan 1. Thus, the statistical null hypothesis of no effect was not rejected. However, until the effects of biotic and abiotic factors are better documented for fish populations in the Wichita River system over a dynamic range of conditions, estimates for present models should be interpreted with caution, and their assumptions considered under the limitations of presently available data. Results are discussed with regard to potential metapopulation structure for these species and possible considerations for future monitoring plans.

Introduction

Stream segments designated as Reaches 5, 6, 7, 9, 10, 11, and 12 in the Red-Wichita River system would be potentially influenced by COE Project Plans to control saltwater inflows to the Wichita River using inflatable dams (Fig. 1). To evaluate this potential influence on spatial distribution of fishes, field sampling was carried out in August 1998 across the Reaches, which included the Wichita River and its tributaries, and Red River tributaries downstream of the Red-Wichita confluence to Lake Texoma. Sample dates coincided with harsh environmental conditions similar to potential conditions under COE Project Plans. This was the end of a very long hot dry summer, when competitive interactions and overlaps in resource use by fishes were likely most intense (Schlosser, 1982; Moyle and Vondracek, 1985). Thus, sharper distinctions were expected for assemblage composition due to abiotic environmental factors (e.g., water temperature, salinity, depth, velocity, land use) and biotic interactions (e.g., predation and competition), than under more benign environmental conditions.

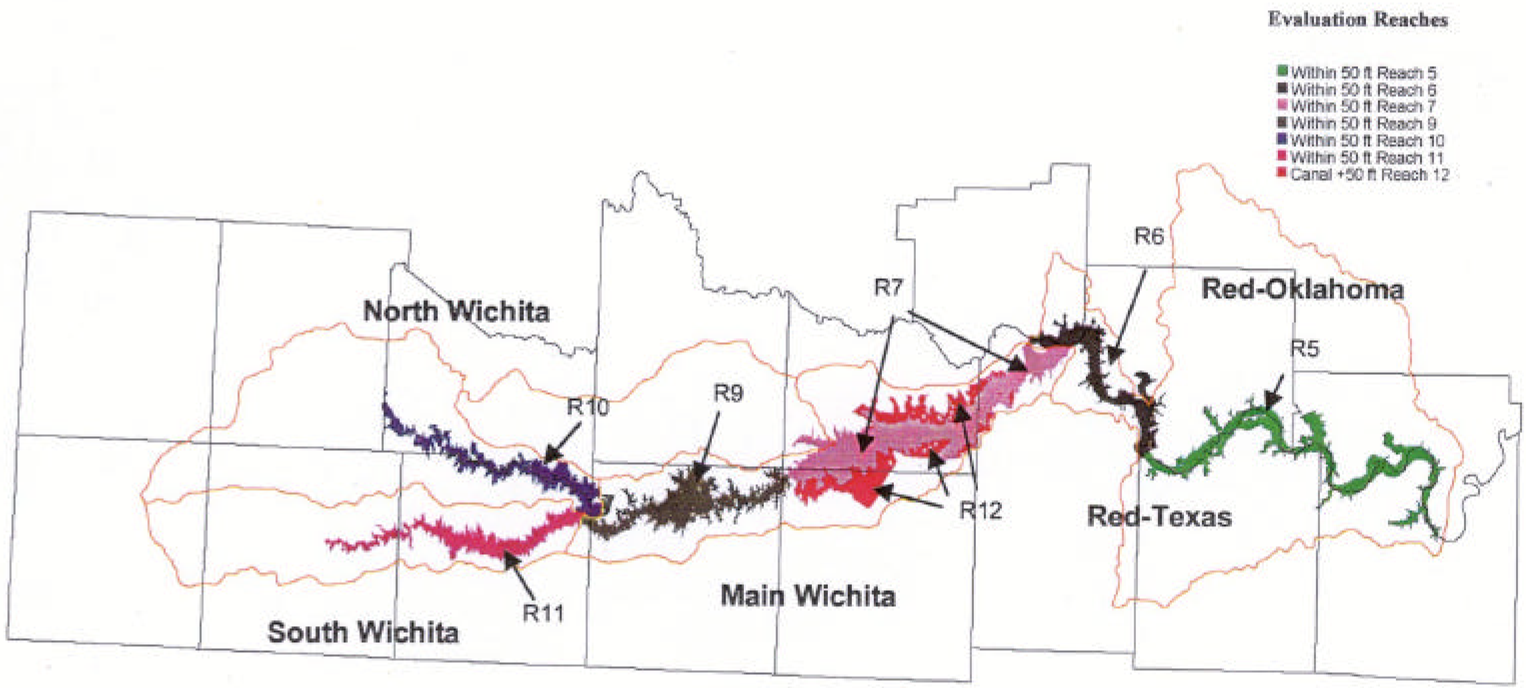
Scenarios Evaluated

The alternative chloride control plan scenarios related to construction and operation of sites VII, VIII, and X (Fig. 2) that served as the basis of the analysis are as follows (Walker, 2000):

Plan 1 - Pre-project conditions (Natural)
Plan 2 - Conditions with Site VIII Chloride Control Only (Current or Base Condition 1998)
Plan 3 - Conditions with Site VIII and Site VII (North Fork Wichita) Chloride Control Only
Plan 4 - Conditions with Site VIII and Site X (Middle Fork Wichita) Chloride Control Only
Plan 5 - Conditions with Sites VIII, VII, and X Chloride Control

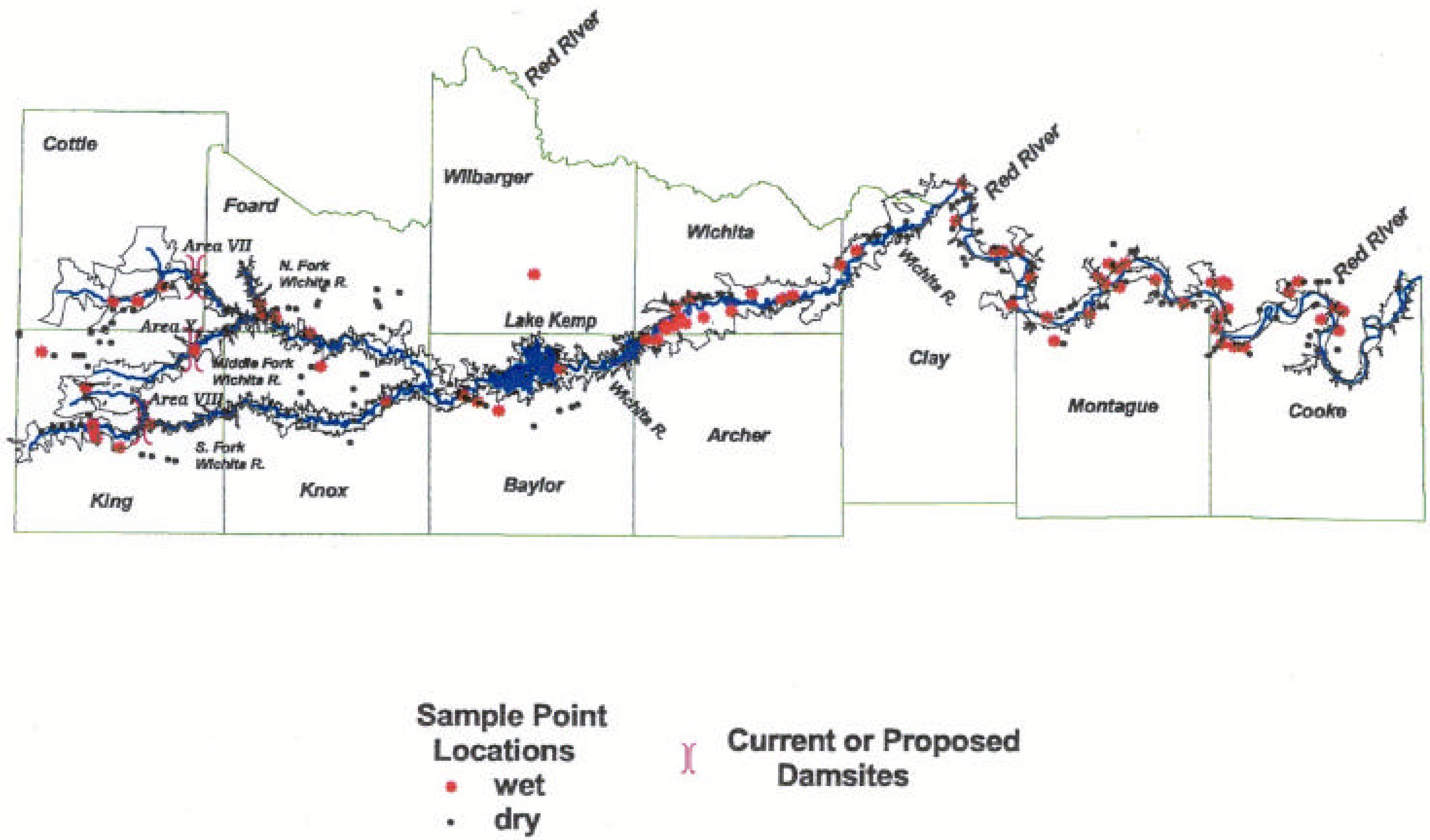
Analytical models were developed to correlate distribution of fish species densities with values for combinations of environmental variables. These variables were grouped into

Figure 1. Evaluation Reaches for Wichita - Red River Chloride Control Study. Reaches 5, 6, 7, 9, 10, 11, and 12 were designated for evaluation. Five reaches (North, South, Main, Red-Oklahoma, Red-Texas) were designated along the drainages to aid in categorizing sites for spatial analysis.



Modified fromWalker (2000)

Fig. 2. Location of wet and dry sample points in relation to area within the 50 ft. evevation rise contour, and location of dam sites operating (Area VIII), in existence, but not operating (Area X), and proposed (Area VII).



three types: land use in the adjacent riparian observed during fieldwork in 1998, land use from contemporary available GIS databases delineated at 50-m and 500-m areas surrounding the sampling sites, and instream physical habitat and physicochemical conditions at sampling sites in 1998. Estimated data under COE Project Plans included the output variables from economics models (McCarl 2000) for land use, and estimates for chloride and Total Dissolved Solids (TDS) were provided by COE. Stochastic estimates for these data were developed with linear regression models and used to estimate related changes in densities of two targeted salt-tolerant species—Red River pupfish, *Cyprinodon rubrofluviatilis*, and plains killifish, *Fundulus zebrinus*.

The following questions were addressed: (1) Among environmental variables related to riparian land use, instream physical habitat and physicochemical water conditions, which combinations are correlated with composition of fish assemblages in these reaches, and (2) are these correlations similar in all reaches or regionalized among some reaches? (3) How is the probability of occurrence for individual species related to change in conductivity, and concentrations of chloride and TDS? (4) What environmental variables are the best predictors of densities of Red River pupfish and plains killifish? (5) How does density of Red River pupfish and plains killifish change under alternative COE Project Plans for control of saltwater inflows to the Wichita River?

Methods

Study sites. The study sites included tributaries of the Wichita River's North, Middle, and South forks, the mainstem, and the tributaries of the Red River in Texas and Oklahoma from the Wichita confluence to Lake Texoma (Figs. 1 and 2). Texas counties sampled included Knox, Archer, Baylor, Clay, Cottle, Foard, Cooke, Wichita, Wilbarger, King, Montague. Two Oklahoma Counties included in the study were Love and Jefferson, located just north of the Red River. A total of 252 sampling sites were established based on access along the mainstem of the Wichita and its tributaries, and tributaries of the Red River. Daily rainfall records from 1965-1997 at U.S. Geological Survey gauges near our sites were used to calculate mean and coefficient of variation for rainfall used in multiple regression analyses.

GIS of watersheds. The data collected for this study was used to build a Geographical Information System (GIS) for the study Reaches. The GIS is in UTM projection, zone 15, and datum Nad83. The data for roads and streams are from Texas Department of Transportation. Land use and land cover categories for Texas and Oklahoma (Table 1) from Walker et al. (2000). The database contains points for all the sampled sites and the sites that were dry. Information on the sites that were dry are important in establishing sites that remain as fish habitat for long term monitoring. The sampled sites that contained water and fish each have tables of environmental and fish data attached to appropriate layers for easy access and map referencing. The GIS also has a layer with 500 m clipped buffers around each sampling site so that land use percentages at 50-m and 500-m scales could be quantified. All land use cells of 800' x 800' for which more than half of the cell was included in the buffer were accepted while cells for which less than half their area was included were rejected. Land-use percentages from each site were calculated, and cells included in the clipped 500-m buffer. The land use data at both spatial buffer values were used as environmental variables in a multivariate

Canonical Correspondence Analysis (see below) to determine how fish densities changed with changes in values of environmental variables. Layers for the two salt-tolerant fish species were created to visualize mapped locations where Red River pupfish and plains killifish were collected (note, many sites on the South Wichita River downstream of the operational Site VIII) were dry during the sampling period). A layer was produced to show the conductivities measured in samples along the Wichita River from East to West. Photographs of upstream and downstream views of sampling locations were taken when samples were made. These have been hotlinked to the GIS, and can be accessed by clicking on the site symbol.

Field sampling. Physicochemical variables measured at each site included conductivity (mSiemens), dissolved oxygen concentration (mg/l), and temperature (oC) were measured with a YSI ® Model 85. At sites with flow the current was measured using a Marsh McBirney Model 2000 Flo-mate ® electromagnetic current meter (cm/s). A suite of riparian and instream habitat variables were visually estimated. These included presence/absence of two dominant substrate types ($\geq$ 15 mm, and < 15 mm longest axis), percent instream area with gravel, percent area of instream cover, presence/absence of five instream cover types, riparian width, percentage of three riparian vegetation types, and presence/absence of eight dominant riparian tree species. Number of each habitat type sampled (e.g. number of pools, riffles, and runs) was recorded as well as its length, width, and depth. At each site the percent bank erosion, maximum bank slope, evidence for degree of flow fluctuation (none, small, moderate, large), and abundance of periphyton (absent, rare, common, and abundant) were recorded. Percentages were converted to proportions and arcsin square root transformed. Categorical variables were transformed into binary (0/1) dummy variables for analyses.

Fishes were sampled with straight seine nets of different lengths (2.4-m, 3-m, and 4.5-m) that were 1.2-m deep with 7.4-mm mesh. All fish greater than 15 cm captured during seine netting were identified and released. Captured fish less than 15 cm in total length were retained, anesthetized with tricane (MS 222), and then preserved in 10% formalin. These voucher specimens were identified, counted, and catalogued into the Texas Cooperative Wildlife Collection in the Department of Wildlife and Fisheries Sciences, at Texas A&M University, in College Station. Fishes were sampled from all habitat types within the sampling unit until no new species were encountered on three consecutive seine hauls. The sites were up to 100 meters long and the abundance of each species was standardized by area sampled for analyses to estimate relative density of each species. Only those species making up > 1% of the overall abundance were used for multivariate analyses.

Reach Groups and Cluster Analyses. To determine if there were differences in spatial distribution of fishes across Reaches (Fig. 1), sites were *a priori* grouped as: North Wichita (Reach 10), South Wichita (Reach 11), Main Wichita (Reaches 7, 9, and 12), Red River tributaries in Oklahoma and Red River tributaries in Texas (Reaches 5 and 6). In order to allow the fish distributions to indicate differences among sites and reaches, a clustering analysis was run to group sites with similar assemblages. Two-way indicator species analysis (TWINSPAN) was used, which classified both species and samples simultaneously using a weighted averaging algorithm (McCune and Mefford, 1995). For this analysis, density was first transformed into pseudo species (nominal variables defined by levels of their abundance). Six levels were chosen to equitably subdivide the frequency distribution of densities across all species. In this analysis they were 0.05, 0.1, 0.2, 0.4, 1.00, and 2.00 fish m-2. The strength of the division between groups is determined by the eigenvalue, with > 0.3 being a strong division and > 0.5 a very strong division (Jongman et. al., 1995).

Table 1. Combined land use/land cover codes of Oklahoma and Texas used for this project, following Walker (2000).

#	Bi-state Code Land Use Names Land Use	Included in Analysis
0	No Data	
11	Urbanized	*
12	Home-farmstead-CAFO	*
13	Highways	*
14	U.S. Air Base	
21	Cropland Dry	*
22	Cropland Irrigated	*
23	Pasture/Hay Dry	
24	Pasture/Hay Irrigated	*
25	Orchard/Speciality Dry	*
26	Orchard/Speciality Irrigated	
28	Savannah	*
31	Range Open	*
32	Range Brushy	*
41	Forest Upland	*
42	Forest Bottoms	*
51	Water Area	*
61	Wetland Non-Forest	
63	Wetland Forest	
64	Urban Flooded	
71	Salt Flats	
72	Sand Dunes	
73	Quarries	*
74	Oil Waste	*
75	River Wash	*
76	Red Badland	*
81	Park-Cemetary	

Some of the land use land cover data was not included in the 500-m and 50-m buffers around the sites so the land use included in the analysis is designated with a *.

Canonical Correspondence Analysis. To determine which environmental variables and species were most strongly associated with either sites grouped by fish (Fish site-groups) or sites grouped by reach (Reach site-groups), a canonical variates analysis (CVA), also called Fisher's linear discriminant analysis, was run using the software package CANOCO (Ter Braak and Smilauer, 1998). CVA is a multivariate technique that chooses the linear combination of independent variables (here alternatively, species densities or values of environmental variables) that best discriminates between groups of sites. Thus, four separate analyses were run to determine which environmental variables and which species characterized each group of sites.

Variation in species distribution was explained separately by five classes of environmental variables (instream, riparian, land use at 50-m and 500-m, Reach site-groups, and Fish site-groups). This variation was measured by running a multivariate canonical correspondence analysis (CCA) using the software package CANOCO (Ter Braak and Smilauer, 1998). CCA is a direct gradient analysis that selects the linear combination of environmental variables that best explains relationships among the dependent variables (here species DENSITY) across the samples (Jongman et al., 1995). To reduce the number of environmental variables needed, yet still explain a significant amount of the variation in species distributions among samples, a Monte Carlo permutation procedure (199 permutations) tested variables for selection into the model (Ter Braak & Smilauer, 1998). Each variable that explained a significant ($P < 0.05$) additional variance (given other variables already in the model) was included. Environmental variables that showed high multi-colinearity with other variables (indicated by variance inflation factors > 20) were excluded from the analysis because they add little additional information (Jongman et al., 1995). Using the final ordination model, a partial CCA was used to measure the variance explained by variables in each of the environmental classes.

For each species, its probability of occurrence was estimated with respect to the range of values only for variables indicating salinity (Conductivity, TDS, and Chloride). Probability of occurrence was calculated using the software package CANODRAW (Smilauer, 1992). For this analysis, probability was modeled separately for each species as a linear function of the variable using a logit link function. Values for Chloride and TDS were calculated from conductivity measured in the field and relationships using conversion equations for reaches provided by COE.

A model was developed for relationships between density of the two salt-tolerant species (Red River pupfish and plains killifish), and target variables that could be influenced by Project Plans (Dry Cropland and Pasture/Hay, Irrigated Cropland, and TDS; see *Risk Analyses* below). The relationship was modeled using linear multiple regression analysis for 1998 data using the software package SAS version 6.12 (SAS, 1989). All of the instream, riparian, and land use environmental variables, as well as mean and coefficient of variation of rainfall, were considered for inclusion in the model. The addition of variables to the model was stopped when the coefficients of all targeted variables became significant.

Risk Analyses. Stochastic models of density for the two salt-tolerant species in each Reach were developed using the program @Risk in Decision Tools Suite (Palisade 1998), and 1998 field data, and for estimated data under the five Project Plans (McCarl 2000). Distribution functions were fitted to the 1998 data for environmental variables in the regression model using the program BestFit (Palisade 1998). The distribution functions were used to generate randomized values (2000 iterations to meet convergence criteria of ±1.5% change in mean and standard deviation) for each dependent variable in the regression model.

Sensitivity analyses for stochastic models of fish density using 1998 data indicated greatest significant correlation coefficients for the variables Dry Cropland, Dry Pasture/Hay, Irrigated Cropland, and TDS. These variables could be estimated using economics models (McCarl 2000) for Reaches and land area within boundaries likely to be affected under COE Project Plans. Estimates output by economics models were in total acres for each land use in each Reach, and only for land already in crop production. Therefore, estimates were for effects of conversion of land use within these categories.

The 1998 study sites were not necessarily located in the same areas considered by the economics models, but sites with target species were only rarely located outside of the evaluation area. Relationships between environmental variables and density used in the regression models were assumed to reasonably apply to these areas as well because they were usually nearby the evaluation areas. Variation under COE Project Plans could not be estimated for environmental variables other than TDS (provided by COE) and land use area estimated by economics models (McCarl 2000), nor could their variability, as estimated by 1998 data, reasonably be assumed to apply. Therefore, models for effects of COE Project Plans on density of fishes included stochastic variability for only those environmental variables that could be reasonably estimated. Effects for other environmental variables in these models were kept at their estimated means for 1998 data (essentially limiting their effects in the regression model to those for 1998 data). Therefore, results of stochastic models are most useful for comparisons of estimated effects in each Reach under each Project Plan.

Results

A total of 252 sites were evaluated; 183 sites were dry, and two had water but no fish (Fig. 2). Wet sites with no fish were likely due to runoff after local thunderstorms. Across the 57 sites that contained fish, 45 species were collected. Red River pupfish were collected at 11 sites (Fig. 3), and plains killifish were collected at 16 sites (Fig. 4). After excluding species that composed less than 1% of the total abundance, 21 species were left in the analyses (Table 2).

Fish Site-Groups and Reach Site-Groups. TWINSPAN identified four groups of sites based on their fish assemblages (Fish site-groups). High eigenvalues (0.351 – 0.446) for each level of differentiation in the analysis, indicated reasonably strong differences among groups. Significant ($P < 0.05$) differences among these groups also were based on environmental variables (Table 3). The percentage of the major differences among groups that could be explained by either environmental data or differences in species composition (i.e., percent variance of Groups x Environmental Data, Table 3) was higher for Fish site-groups (57.3% and 45.1% for species and environmental variables, respectively) than for Reach site-groups (29.0% and 34.1% for species and environmental variables, respectively). This indicated that major differences among site groups (i.e., variation explained by the first axis) based on their fish assemblages were related to environmental variables as well as species density, but only weakly related to spatial location in the watershed. Also, that species densities were best for discriminating among Fish site-groups (i.e., explained more variation), and environmental variables were best for discriminating among Reach site-groups (Table

3). Thus, while environmental conditions differed among site groups with regard to their spatial location in Reaches, these differences were not well correlated with differences related to fish distribution.

The major differences among Reach site-groups were related to a complex spatial gradient for environmental variables that ran from southwest to northeast across the study area (as indicated by the significant correlation of longitude with axis one, Table 4). Across this gradient, Dissolved Oxygen concentration (DO) decreased (indicated by a negative Canonical Coefficient, Table 4) and area of Forested Uplands in the watershed increased (indicated by a positive Canonical Coefficient, Table 4). Bluegill (*Lepomis macrochirus*, LEMA) was the only species that discriminated among Reach site-groups (positive Canonical Coefficient, Table 4), and indicated higher densities of bluegill at sites with higher DO and more Forested Uplands as one moved northeast across the area.

Table 2. Scientific name, common name, and code for the 21 species which made up >1% of the overall abundance were used for analyses (Species are ordered from highest to lowest abundances)

Scientific Name	Common Name	Code	Total # Collected
Cyprinella lutrensis	Red Shiner	CYLU	2344
Gambusia affinis	Mosquitofish	GAAF	1567
Lepomis megalotis	Longear Sunfish	LEME	750
Cyprinodon rubrofluviatilis	Red River Pupfish	CYRU	695
Pimephales promelas	Fathead Minnow	PIPR	684
Pimephales vigilax	Bullhead Minnow	PIVI	579
Fundulus zebrinus	Plains Killifish	FUZE	425
Lepomis cyanellus	Green Sunfish	LECY	359
Lepomis humilis	Orange-spotted Sunfish	LEHU	336
Amerius melas	Black Bullhead	AMME	333
Lepomis macrochirus	Bluegill	LEMA	302
Menidia berylina	Inland Silverside	MEBE	297
Dorosoma cepedianum	Gizzard Shad	DOCE	230
Campostoma anomalum	Central Stoneroller	CAAN	142
Micropterus salmoides	Largemouth bass	MISA	79
Lepomis gulosus	Warmouth	LEGU	52
Phenacobius mirabilis	Suckermouth Minnow	PHMI	50
Notemigonus chrysoleucas	Golden Shiner	NOCR	34
Pomoxis annularis	White Crappie	POAN	27
Amerius natalis	Yellow Bullhead	AMNA	15
Carpiodes carpio	River Carpsucker	CACA	10

Fig. 3. Locations of sample points with fish that had Red River Pupfish present or absent in relation to chloride concentration and location of dam sites operating (Area VIII), in existence, but not operating (Area X), and proposed (Area VII).

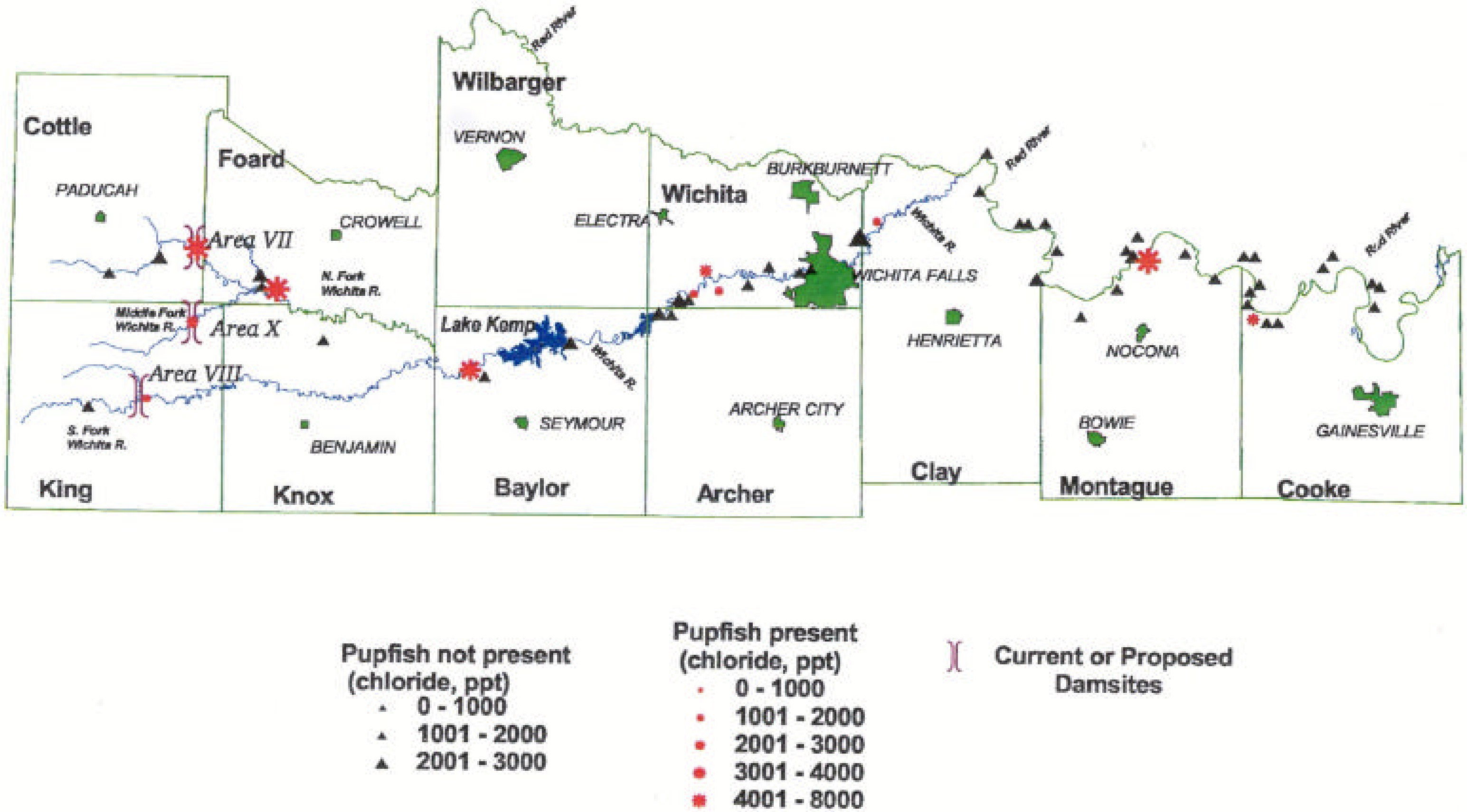


Fig.4 . Location of sample points with fish that had Plains Killifish present or absent in relation to chloride concentration and location of dam sites operating (Area VIII), in existence, but not operating (Area X), and proposed (Area VII).

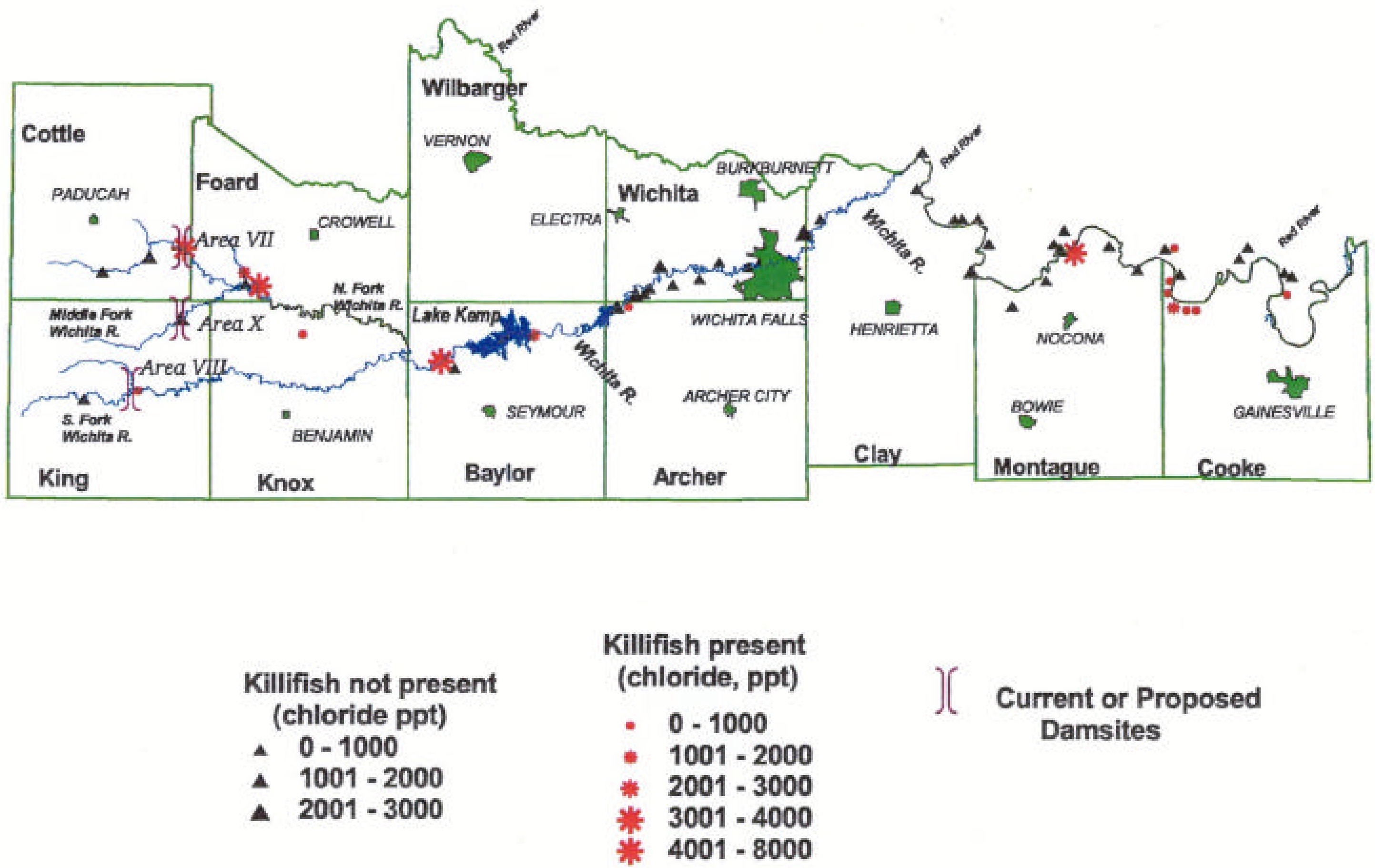


Table 3. Canonical variates analysis for site groups clustered by fish and by reach location, using CPUE of fish species and values for all significant environmental variables

Group		Reaches		Sites (fish)	
Explanatory Variables		Species	All Env	Species	All Env
Variance (eigenvalue)	1st Axis	0.161	0.922	0.700	0.590
Groups X Explanatory Variables Correlation	1st Axis	0.401	0.960	0.837	0.768
Percent of Total Variance	1st Axis	4.000	23.000	23.300	19.700
Percent of Total Variance that was Explainable by Variables	1st Axis	29.000	34.100	57.300	45.100
Total Variance (eigenvalues)		4.000	4.000	3.000	3.000
Total Explained Variance (canonical eigenvalues)		1.610	2.706	1.222	1.308
P-value		0.045	0.005	0.010	0.005
Percent Explained	Total	0.403	0.677	0.407	0.436

Table 4. Canonical coefficients and inter-set correlations of sites clustered by fish groups for axis 1 resulting from the canonical variates analyses on fish groups (Significant ($P<0.05$) values are indicated in bold)

Environment	Canonical Coefficient	Inter set Correlations
Temperature	0.1503	0.2614
Conductivity	**0.7515**	0.465
Number Species	**-0.5171**	-0.3238
% Tree	0.3920	-0.0786
% Instream cover	-0.3912	-0.2594
Number Glides	**0.7818**	0.4241
Mesquite	**0.7060**	0.3430
Fish Species	Canonical Coefficient	Inter set Correlations
CYRU	0.0204	-0.0285
FUZE	**1.8329**	0.8355
LECY	0.0725	-0.0073
NOCR	0.0721	-0.0151

The CVA for Fish site-groups (Table 5) discriminated between sites with lower Number of Species and higher Conductivity, more Glides, and higher probability of Mesquite in the riparian zone, compared to sites with more species, low Conductivity, and low probability of Mesquite in the riparian zone. Densities of Red River pupfish, plains killifish, green sunfish (*Lepomis cyanellus*), and golden shiner (*Notemigonus chrysoleucas*) were each positively associated with a different Fish site-group. However, only plains killifish (FUZE) significantly ($P < 0.05$) discriminated among Fish site-groups (Table 5).

Table 5. Canonical coefficients and inter-set correlations of sites clustered by reach for axis 1 resulting from the canonical variates analyses on reaches (Significant ($P<0.05$) values are indicated in bold)

Environment	Canonical Coefficient	Inter set Correlations
O2	**-0.3409**	-0.0666
% Shrub	0.1593	0.4352
Number Runs	-0.1489	0.0416
Presence\Absence Fine	0.029	0.2584
Presence\Absence Coarse	-0.0191	-0.0549
Juniper	-0.009	0.0355
Forest Upland 500 m	**0.4465**	-0.2359
Forest Bottomland 500 m	0.1898	-0.2523
Red Badlands	0.1729	0.2298
Longitude	**-3.6993**	-0.9433
Latitude	0.0902	-0.3507
Urbanized at 50 m	-0.0276	0.2208
Fish Species	Canonical Coefficient	Inter set Correlations
LEMA	**1.0915**	0.4008

Quantitative Relationships Between Fish-Assemblage Composition and Environmental Variables. Together, the CCA using all environmental variables, and the nominal variables identifying Fish and Reach site-groups, accounted for 62.7% of the variation in species densities among sites (Table 6). The CCA identified a complex gradient of fifteen environmental variables that were correlated with species densities (Table 7). Four instream variables (including Conductivity) explained 9% of the variation in species densities (Table 6)—Conductivity and Number of Runs were significant on the major (first) axis, and Number of Species was significant on the second axis (Table 7). Two riparian variables explained 5.5% of the variance (Table 6), but only Tree Canopy was significant (on axis four, Table 7). Three land use/land cover variables explained 11.6% of the variation in species density (Table 6)—Pasture/hay Dry Land Use at 50-m and 500-m scales on the second axis, and Forested Upland at 50-m scale on CCA axes three and four (Table 7). Two Reach site-groups— North Wichita and Red-Oklahoma—explained 4.5% of the variation in species densities among sites (Table 6) and effects of both were significantly related to CCA axis two (Table 7). The Fish site-groups explained 12% of the variation in species densities (Table 6) and were significantly related to each of the first four CCA axes (Table 7). Because the four Fish site-groups were mutually exclusive the fourth group had no explanatory value beyond that already due to the other three (Table 7).

Table 6. Results of the partial canonical correspondence analysis of all environmental and group variables for fish collections in the Wichita River System and Red River tributaries from the confluence with the Wichita River to Lake Texoma

	Axes	All Variables	Environmental Variables: Instrm +cond	Conduc t-ivity	Riparian	Land Use	Env	All Reach	Fish Group
Eigenvalues	1	0.583	0.211	0.028	0.184	0.327	0.383	0.127	0.346
	2	0.528	0.13	0.332	0.082	0.133	0.345	0.092	0.175
	3	0.449	0.078	0.253	0.332	0.105	0.226	0.332	0.064
	4	0.353	0.02	0.234	0.253	0.332	0.18	0.253	0.332
Species X Env Correlations	1	0.955	0.848	0.44	0.817	0.924	0.913	0.746	0.908
	2	0.941	0.654	0	0.686	0.725	0.911	0.69	0.797
	3	0.923	0.723	0	0	0.681	0.839	0	0.626
	4	0.915	0.392	0	0	0	0.779	0	0
Cumulative Percent Variance of Species Data	1	12	9.4	1.5	8.9	13.8	11.6	6.3	14.5
	2	22.9	15.2	19.6	12.8	19.3	22	10.8	21.7
	3	32.1	18.6	33.3	28.8	23.8	28.9	17.2	24.4
	4	39.4	19.5	46.1	41	37.7	34.3	19.6	38.3
Explainable by Variables	1	19.1	48.1	100	69.3	57.9	25.7	56.1	59.2
	2	36.4	77.8	0	100	81.4	48.8	100	89
	3	51.1	95.5	0	0	100	63.9	0	100
	4	61.8	100	0	0	0	76	0	0
Uncounstrained Eigenvalues	Total	4.859	1.15	1.839	2.077	2.376	3.303	2.01	1.347
Canonical Eigenvalues	Total	3.047	0.439	0.028	0.265	0.564	1.491	0.219	0.585
P-value	1	0.005	0.035	—	0.005	0.005	0.02	0.04	0.005
	Total	0.005	0.02	0.705	0.005	0.005	0.005	0.005	0.005
Percent Explained	Total	62.7	9.0	0.6	5.5	11.6	30.7	4.5	12.0

Table 7. Canonical coefficients and Inter set correlation results of the canonical correlation analysis of all variables

	Canonical Coefficients				Interset correlations			
Variable	AX1	AX2	AX3	AX4	AX1	AX2	AX3	AX4
Conductivity	0.3828	-0.2092	-0.1546	-0.0156	0.2357	0.4352	-0.3205	0.1652
Num Species	0.1656	-0.3481	-0.1306	0.0528	-0.0263	-0.5533	-0.4019	-0.0136
Area Pool	-0.0805	0.0427	-0.0468	-0.0336	0.0574	-0.1449	-0.0559	0.0187
% Shrub	0.0834	-0.031	-0.2321	-0.1325	0.2165	0.0834	-0.2649	-0.2982
Tree Canopy	-0.0242	-0.0821	-0.0737	-0.4472	-0.3054	-0.4749	0.0317	-0.0374
Num Runs	0.3771	-0.0574	0.1785	0.1792	0.4518	-0.3288	-0.1977	0.1435
Pasture/Hay 500	-0.4369	0.442	0.3243	0.4537	-0.5354	0.1145	0.4756	0.2849
Pasture/Hay 50	0.1059	-0.404	0.1374	-0.1457	-0.1409	-0.0126	0.3088	-0.0029
Forest Upland 50	-0.0609	-0.0834	0.2253	0.9892	-0.1647	-0.1219	0.2165	0.742
North Wichita	-0.2131	-0.3454	0.1755	0.2375	0.3213	-0.1124	0.1999	-0.027
Red River Ok3a	-0.1839	-0.527	0.1724	-0.2071	-0.5567	-0.1594	0.2658	-0.08
Fish Group 1	-2.5939	-0.0984	-1.8483	0.6125	-0.7434	0.1575	0.1238	-0.3556
Fish Group 2	-1.9289	-0.7826	-2.1158	0.8793	0.3554	-0.6472	-0.2413	0.3375
Fish Group 3	-1.2016	0.7957	-1.4585	0.6107	0.2535	0.6908	-0.3475	0.176
Fish Group 4	0	0	0	0	0.5108	0.1277	0.7162	-0.1901

Interpretation of Ordinations and Relationships Between Fish Density and Environmental Variables. The results of the CCA for species and environmental variables were plotted to visualize their relationships (Figs. 5, 6, and 7). Vectors for environmental variables point the direction of increasing magnitude across all sites. Although vectors are only shown for one direction, they also extend in the opposite direction (decreasing magnitude). Longer vectors indicate stronger gradients, and vectors forming more acute angles with an axis had a stronger correlation with the axis. For example, sites to the right on the first axis had more area of land use in Pasture Hay at 50-m and 500-m buffers, and more Runs in the stream habitat (Fig. 5).

Species centroids that are closer to a vector in the plots indicate stronger correlation of species densities with the variable, and the centroid location indicates the optimum value of density with respect to that variable in the samples. For example, density of Red River pupfish (CYRU) was strongly positively correlated with Conductivity, and optimal values were at the maximum values, while it was strongly negatively correlated with Number of Species, and optimal values were at the minimum number of species (Fig. 5).

Nominal variables for Fish site-groups and Reach site-groups are plotted as centroids indicating centers of distribution for sites based on their group membership. Thus, Red River pupfish were the predominant fish species at sites in Fish site-group number 3 (Figs. 5 and 6), which had higher Conductivity. The density of plains killifish (FUZE) was correlated with Fish site-group number 4, which was less strongly correlated with Conductivity, and more strongly correlated with (closer to the vector for) number of Runs in the habitat (Fig. 5 and 6). Centroids for Reach Groups North and Red River Oklahoma were correlated with the second axis (Table 7, Figs. 5 and 7). Thus, densities of Red River pupfish and plains killifish were lower in those reaches than densities for most other fishes (Fig. 5).

Fish site-group one had sites with more green sunfish (*Lepomis cyanellus*, LECY), which was the indicator for this group (Fig. 5, Table 5), more bullhead catfishes (*Ameiurus melas*, AMME; *A. natalis*, AMNA), and more area in Pasture/hay dry land use. It also had more sites in the Red River-Oklahoma group (Figs. 6 and 7). Fish site-group two included sites with more Species and Runs, and larger Total Pool Area (Fig. 5). It also had more sites in the North-Wichita Reach (Fig. 7) with higher Percentage of Shrubs in the riparian habitat, and included higher densities of fathead minnows (*Pimephales vigilax*, PIVI) and red shiners (*Cyprinella lutrensis*, CYLU) (Fig. 5). On CCA axis four, central stonerollers (*Campostoma anomalum*, CAAN) were most dense at sites with more Upland Forest at 50-m buffers (Fig. 5b). The mainstem Wichita Reach site-group had more Runs, and contained species in Fish site-group two. Largemouth bass (*Micropterus salmoides*, MISA) and longear sunfish (*Lepomis megalotis*, LEME) were denser at these sites, which had more Upland Forest area (Fig. 5).

Probability of Occurrence of Species Related to Conductivity, Chloride and TDS. The probability of occurrence for individual fish species across the study sites as related to indicators of salinity—Conductivity, Chloride, and TDS —is shown in Figure 8. If a clear optimum could be modeled for a species, the probability distribution peaked and then decreased along the distribution of values for 1998 data. Species with no clear optimum had a humped shaped distribution. For most species, highest probability of occurrence was at lower values for salinity variables. The two salt-tolerant species and one estuarine species—inland silversides (*Menidia beryllina*)—had optimal occurrence at higher values for salinity-related variables. Mosquitofish (*Gambusia affinis*) and red shiners had a broad probability of distribution across a wide range of values, as did green sunfish and Gizzard shad (*Dorosoma cepedianum*), albeit the latter were at overall lower probabilities.

Linear Multiple Regression and Stochastic Models Relating Environmental Variables to Densities of Target Species. The regression model was fitted to explain a maximum R2 for each species, while maintaining significant coefficients for targeted environmental variables (Table 8). Initial attempts to fit the model indicated a better fit to the 1998 data (higher R2) when sites in Reaches 6 and 8 were modeled separately from those in 9-11. Data for Red River pupfish came from two sites in Reaches 5 and 6, and four sites in Reaches 7 and 12, one site in Reach 9, three sites in Reach 10, and one site in Reach 11 (Fig. 3). Data for Plains killifish came from eight sites in Reach 6 (they were not collected from any site in Reaches 7 and 12), three sites in Reach 9, four sites in Reach 10, and one site in Reach 11 (Fig. 4).

The stochastic models for individual Reaches used coefficients for environmental variables derived from their respective combined-reach regression models. The predicted means for each Reach, and all Reaches combined, were within $\pm$1 standard deviation (SD) of 1998 data. The mean, $\pm$ 1 SD, 5th %tile, and 95th %tile for estimated density of each species for combined Reaches are plotted in Figure 9.
These can be compared to estimates under COE Project Plans 1 and 2 (pre-project and present project conditions, respectively), and Plans 3-5 (expanded project conditions), which are plotted separately for Reaches 6 and 8 (Figs. 10 and 11), and Reaches 9-11 (Figs. 12 and 13). Differences among Project Plans were due only to changes in the estimated values for land use variables and TDS.

Differences between results for 1998 data and COE Project Plan 2 (present project conditions), were assumed to be mainly caused by differences in types of variability estimated. Variability for 1998 data was spatial variability for actual field data, whereas variability for each Project Plan was based on estimated mean value of a variable for each reach across time projections, provided by economics models (McCarl 2000 for land use) and COE data (for TDS). Across all models, each estimated mean $\pm$ 1 SD, was within $\pm$ 1 SD of 1998 distributions.
For Red River pupfish in Reach 6, estimated density for pre-project and present-project conditions (Plans 1 and 2 respectively) were similar. For Reach 6 (nearest to the Wichita-Red River confluence), the low-range estimates for Plans 3-5 (-1 SD, 5th % tile) were below those for Plan 2 (Fig. 10), but were similar for Reach 5 (furthest from the confluence). For Reaches 7 and 12, density of Red River pupfish declined from pre-project (Plan 1) conditions to present Project conditions (Plan 2, Fig. 10), and further declined under conditions of expansion alternatives for Plans (3-5). For Reach 12 (Wichita County Irrigation District), low-range estimates of Red River pupfish density under Plans 3-5 were below those for Plan 2 (Fig. 10).

Table 8. Regression coefficients for models of $\log_{10}$ density of plains killifish and Red River pupfish in tributaries andmainstem reaches of Wichita River and tributaries of Red River based on 1998 field data*

	Reaches 6 & 8		Reaches 9, 10 & 11	
	Plains killifish	Red River pupfish	Plains killifish	Red River pupfish
	$R^2 = 0.998$	$R^2 = 0.994$	$R^2 = 0.999$	$R^2 = 0.999$
Intercept	17.68186	5.79858	6.12064	26.98161
Land Use/Large-scale variables:				
% CropsDry 500m	-0.46957	-0.26608	1.76624	0.44947
% CropsIrrigated 500m	1.08838	-2.50330	-2.19306	6.37560
% PastureHayDry 500m		-0.87133		
% PastureHayDry 50m		0.44150		
% OrchardSpecialtyDry 500m		-2.02567		
% HomeFarmConfinedAnimal 50m	-0.57569			0.11238
% ForestedBottomland 500m		2.28930		
% ForestedBottomland 50m		-0.99966		
% ForestedUpland 50m	-0.41826			
% RangeBrushy 50m		0.20131		
% RangeOpen 500m	-0.77002	-0.52644	-0.12050	-0.12417
% RiverWash 500m	-2.81404			
% Highways 500m	-3.26644	13.22064		
% Quarry 500m	1.40537			
% OilWaste 50m	1.38685			
% WaterArea 500m		-1.01458		
Longitude	-0.00004		-0.00001	
Mean Daily Rainfall				-13.88502
CV Mean Daily Rainfall	-2.68606			
Instream variables:				
TDS	0.00003	0.00021	0.00006	0.00017
Temperature			-0.03288	
Max. Bank Slope			0.02576	
Max. Depth			0.03823	0.12777
No. Bends		-1.13137		
No. Pools	0.14856		-0.94532	0.03076
No. Riffles	0.10986			
No. Runs	-0.10934			
Total Length			-0.00625	
Total Riffle Length				-0.74844
P/A Coarse substrate	-0.16364		0.54828	
P/A Fine Substrate		0.30567	-1.64640	
P/A Rootwads	-0.37385			
P/A Woody debris	0.14339			
Area Riffles			-0.16641	
Area of pools	-0.40247	-0.44401		
Riparian variables:				
% Grass	-2.45775	-1.44467		
% Gravel		0.52312		-1.77679
% Trees	-2 .47034			
% Instream Cover		-3.35678		
% Max Bank Erosion		1.18974		
P/A Cottonwood	0.35791		-1.09785	
P/A Hackberry	-0.64540	1.50312		
P/A Mesquite	-0.63467	1.31563		
P/A Oak	0.22864			
P/A Pecan	-0.23537	-0.71951		
P/A Saltcedar		-0.99599		0.53615
P/A Willow		-0.61342		-2.07300
P/A Grass			-0.02070	-0.59893
P/A Sedges	1.47853			
P/A Typha				-0.51298
P/A Human Disturbance		-0.39285		

*Values are shown for variables included in models for each species and reach. Variables in bold are those for which distribution functions were fitted to model stochastic variability of fish densities (keeping other variables constant at their average values). For stochastic models, distribution functions under COE Plans 1-5 were fit to estimated data for TDS provided by COE, and for land use provided by economics models in McCarl (2000). Categorical variables are indicated as presence or absence (P/A), and percentage data by %

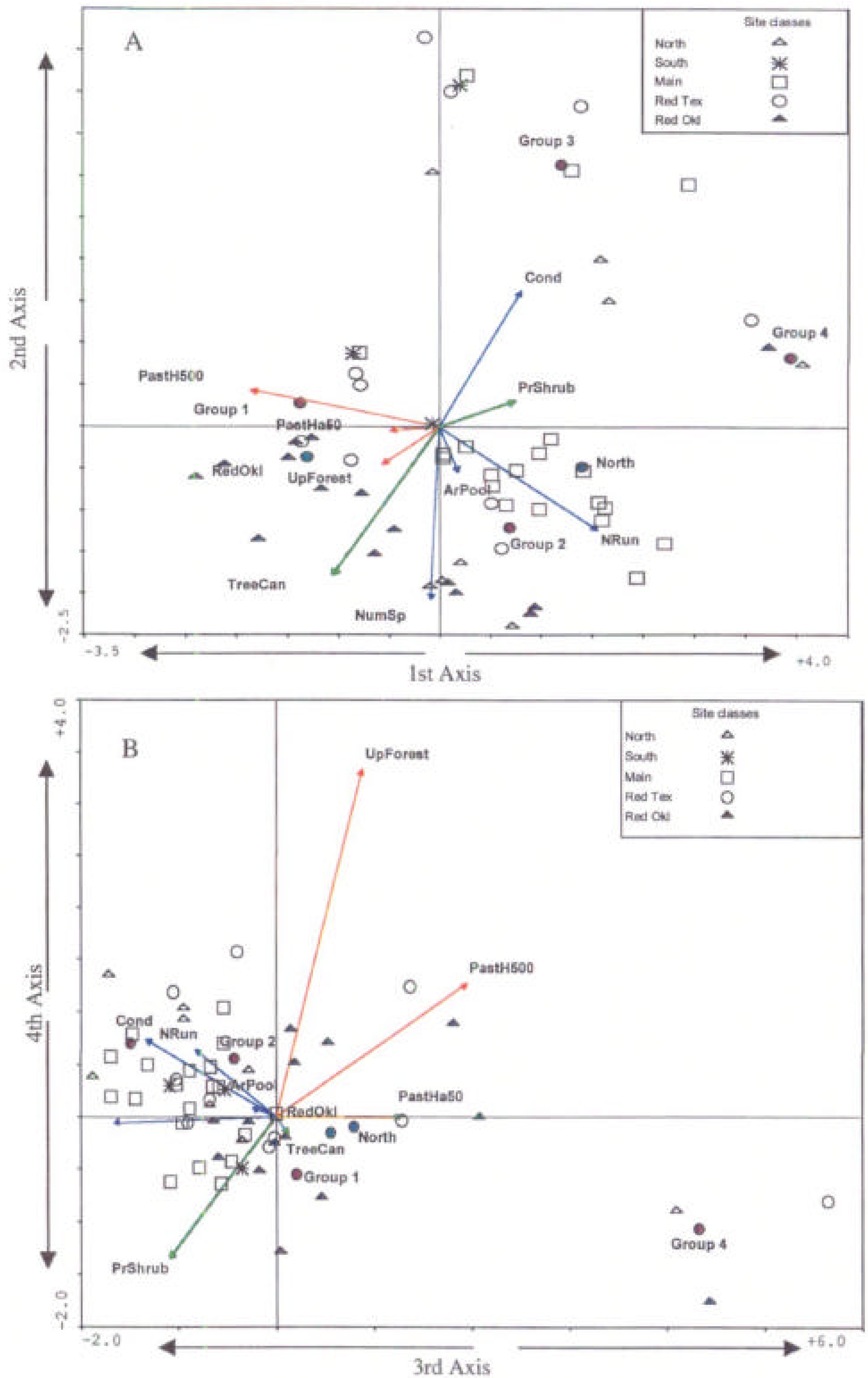


Figure 7. Plot of sites coded by groups based on reach classification and relationships to environmental variables on the first and second (A) and third and fourth (B) canonical axes.

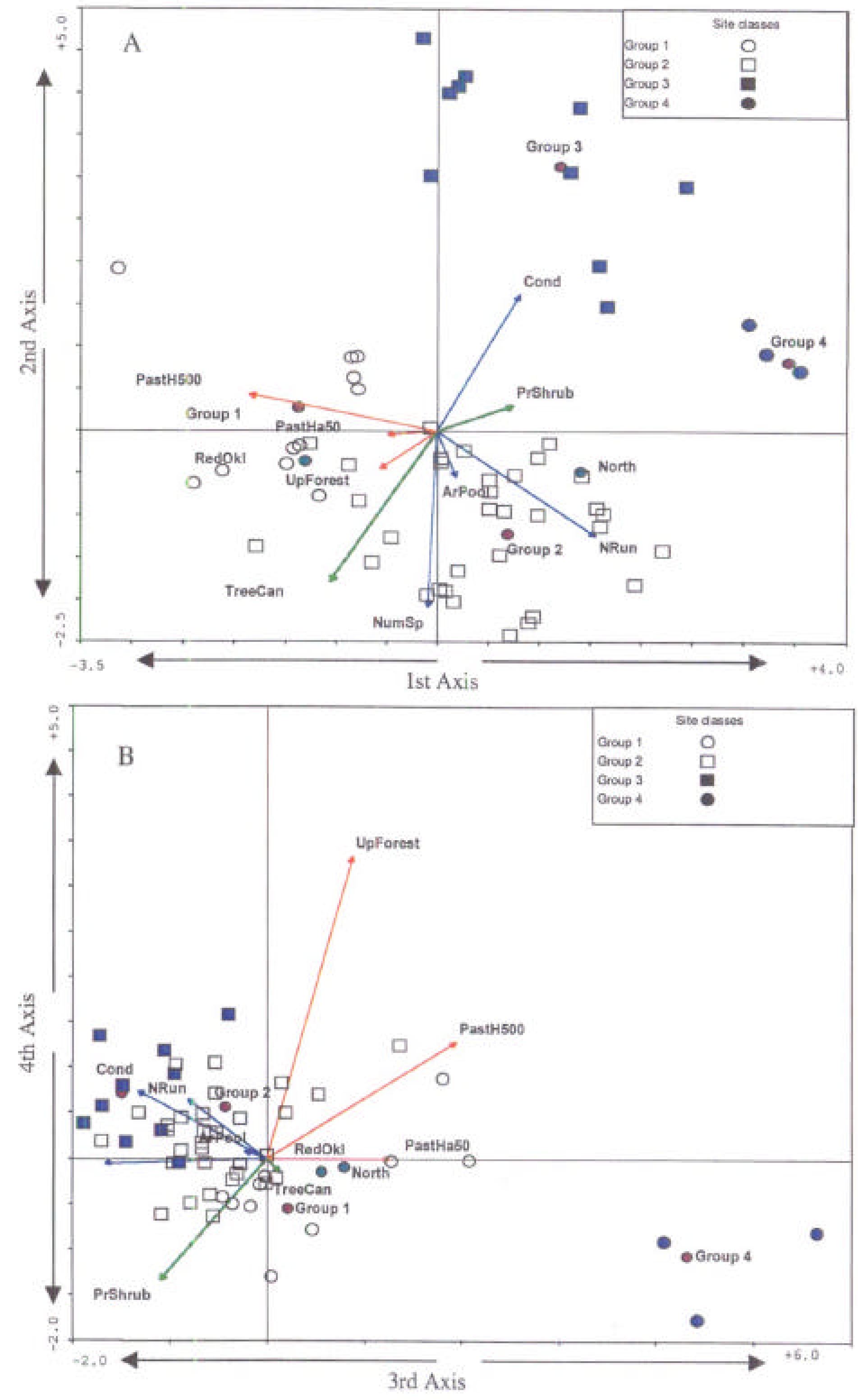


Figure 6. Plot of sites coded by groups based on fish distribution and relationships to environmental variables on the first and second (A) and third and fourth (B) canonical axes.

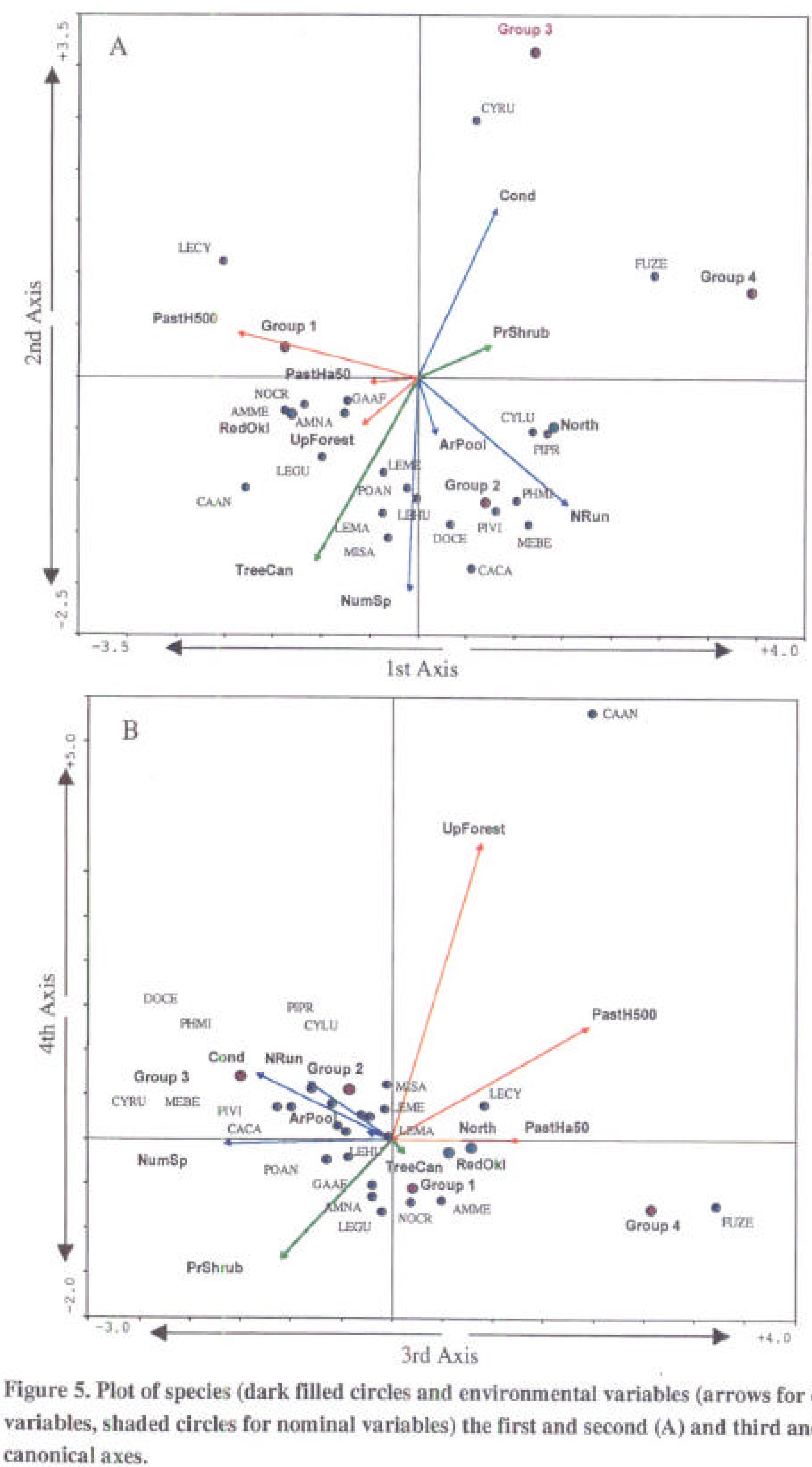


Figure 5. Plot of species (dark filled circles and environmental variables (arrows for quantitative variables, shaded circles for nominal variables) the first and second (A) and third and fourth (B) canonical axes.

Figure 8a. Probability of occurrence of fish species related to conductivity.

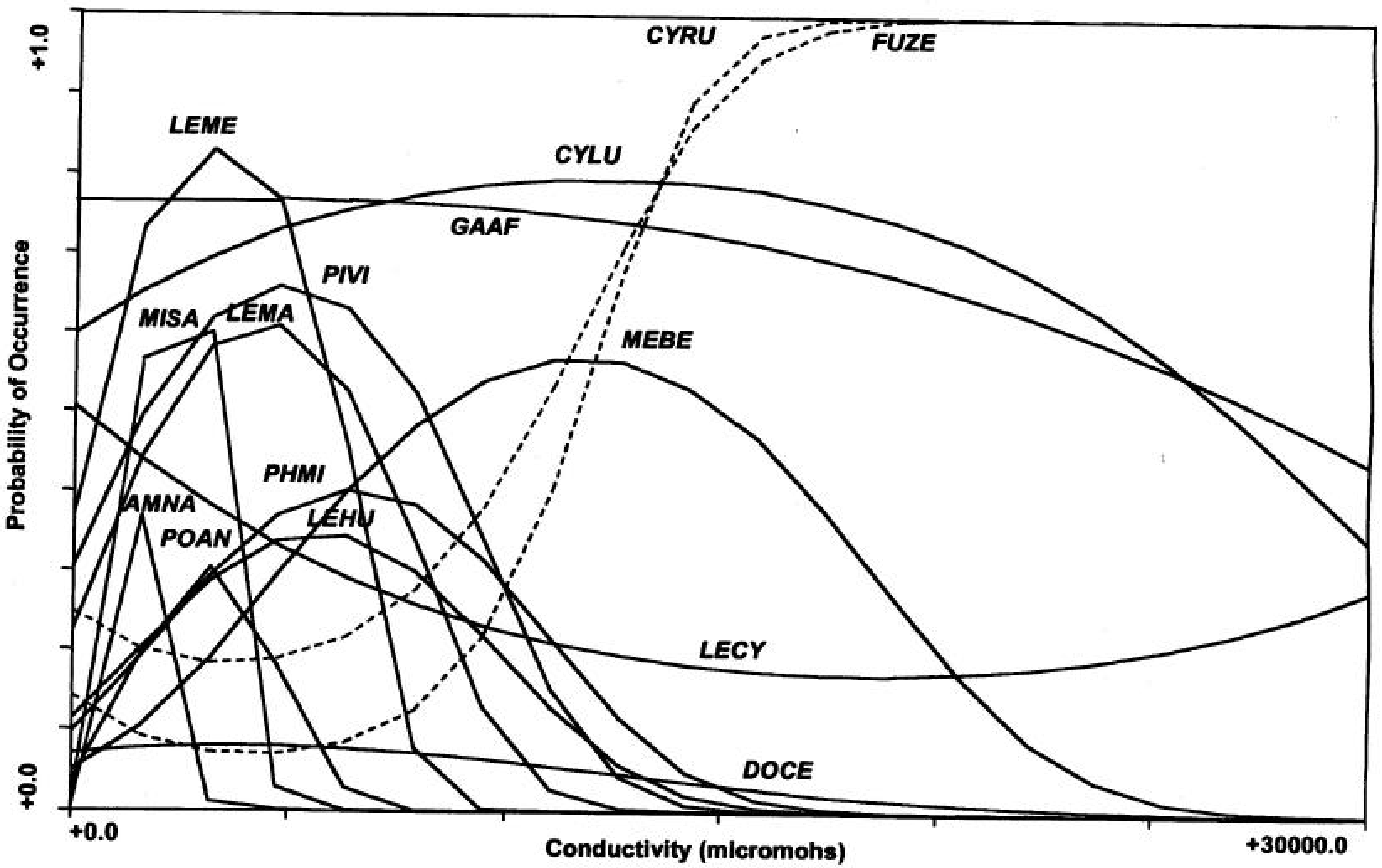


Figure 8b. Probability of occurrence of fish species related to Chloride concentration.

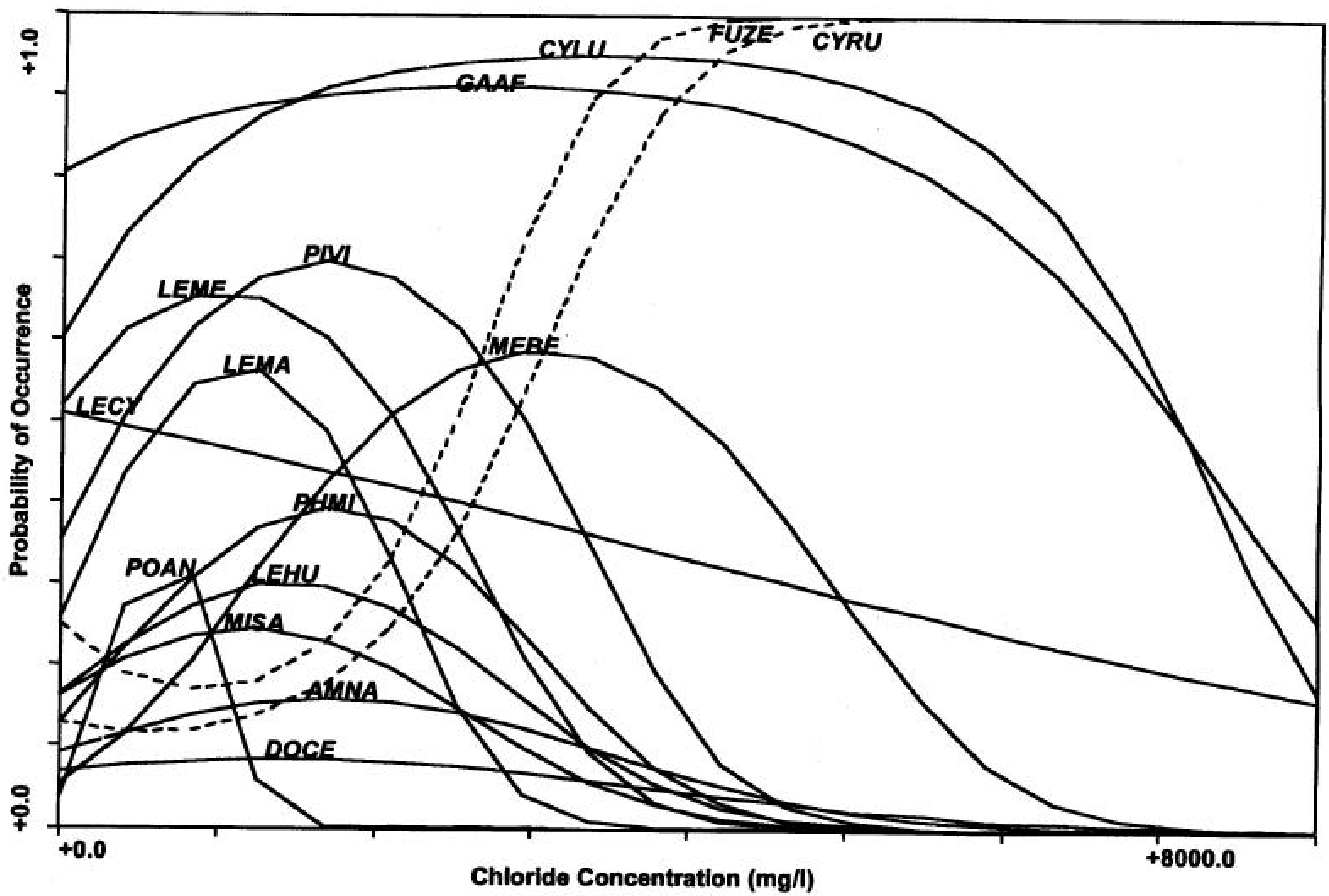


Figure 8c. Probability of occurrence of fish species related to concentration of Total Dissolved Solids.

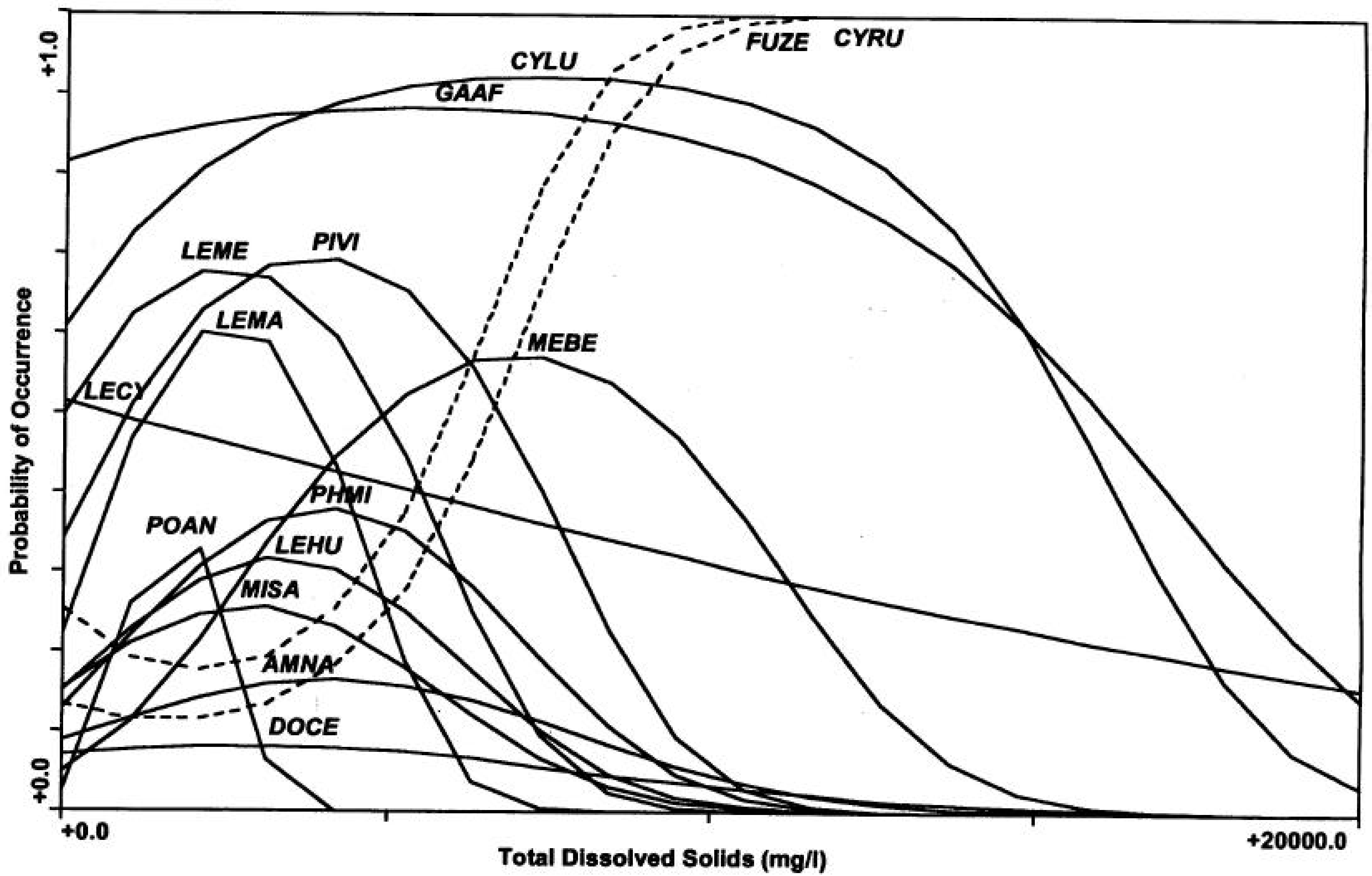


Figure 9. Results of stochastic models of density (CPUE) for Red River pupfish and plains killifish in Wichita and Red River study reaches based on 1998 field data.

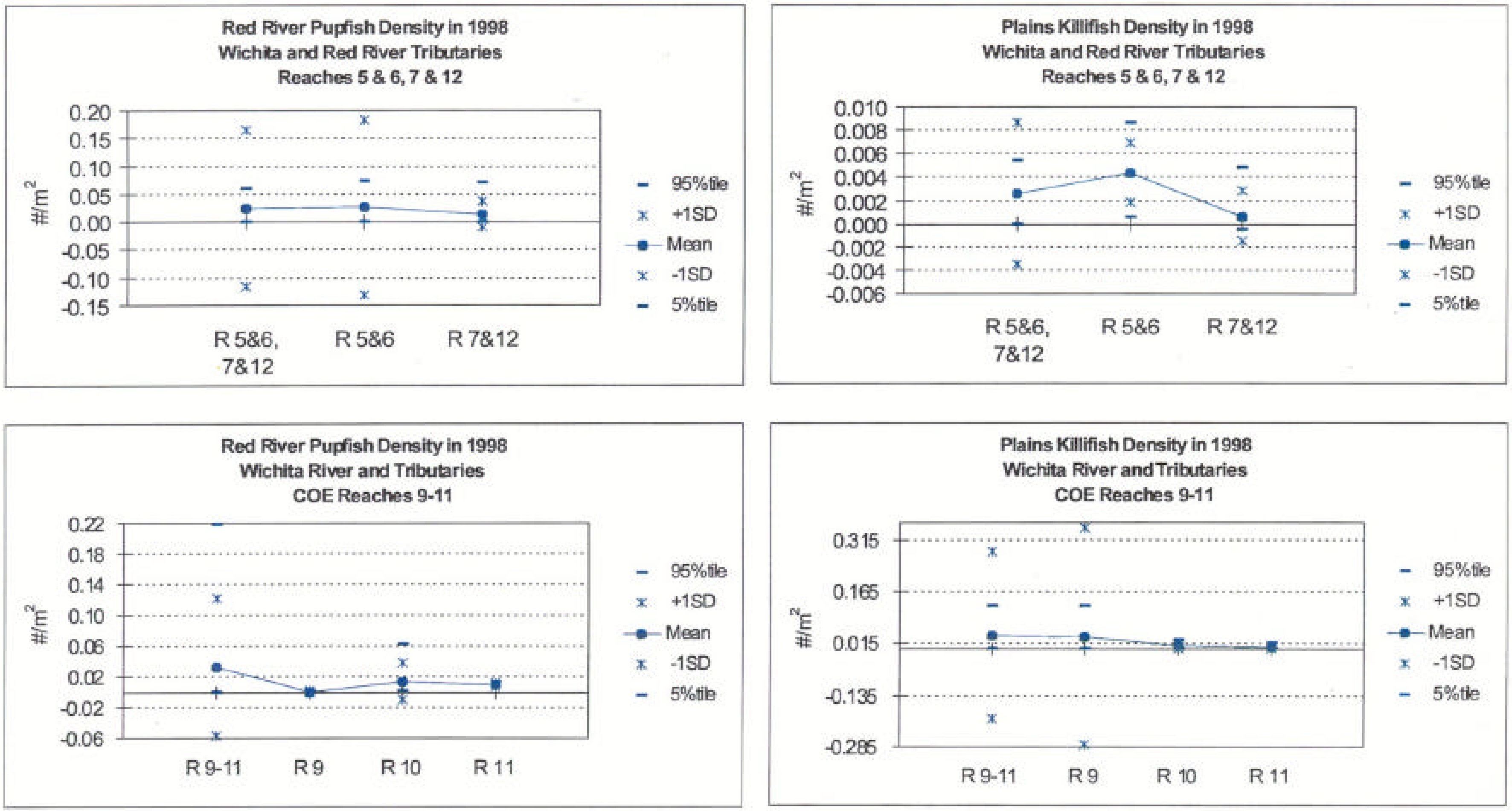


Figure 10. Results of stochastic models of density (CPUE) for Red River pupfish in Wichita and Red River study reaches based on 1998 field data and estimates for TDS and land use for Reaches 5 & 6 and 7 & 12 under COE Project Plans 1-5.

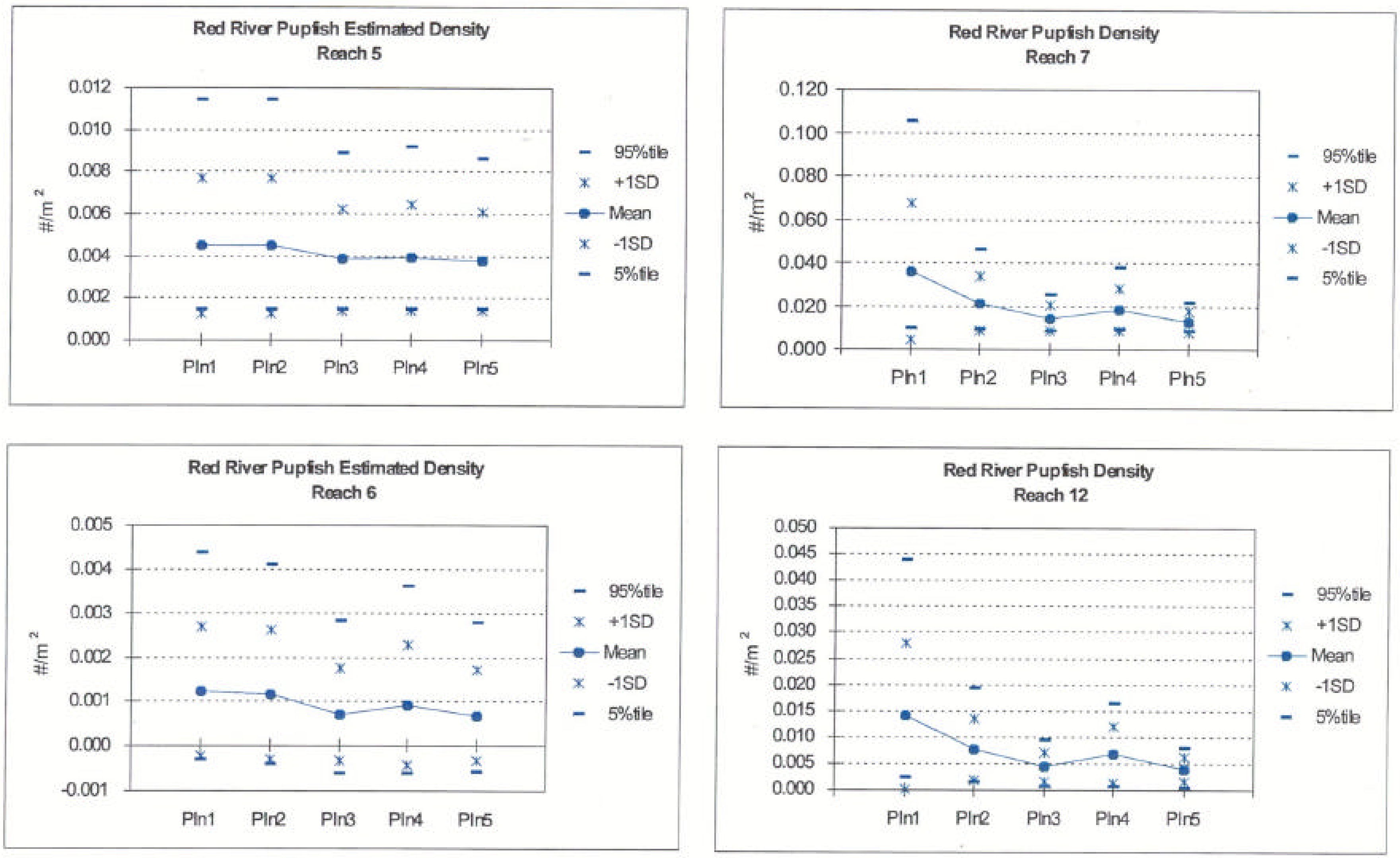
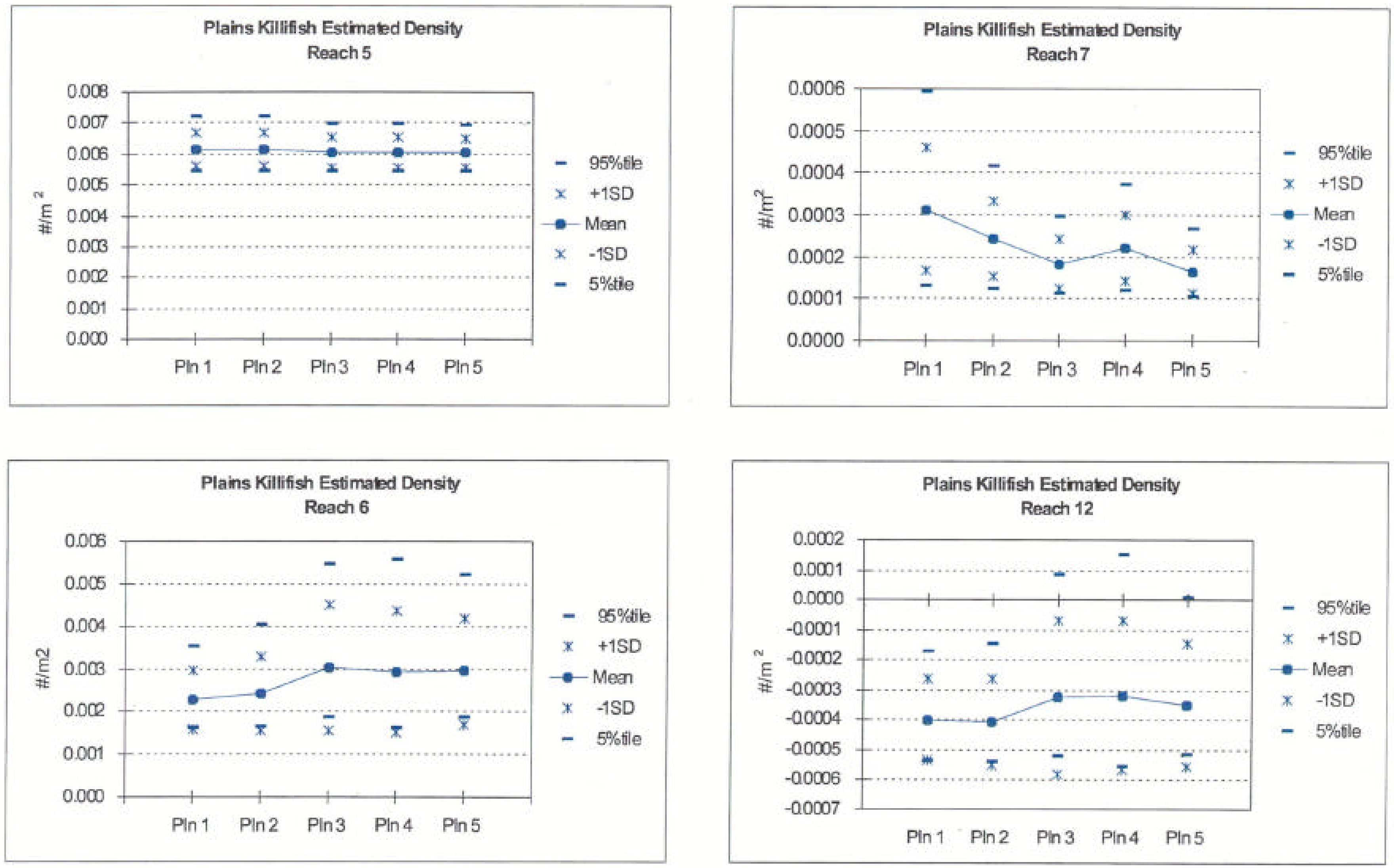


Figure 11. Results of stochastic models of density (CPUE) for plains killifish in Wichita and Red River study reaches based on 1998 field data and estimates for TDS and land use for Reaches 5 & 6 and 7 & 12 under COE Project Plans 1-5.



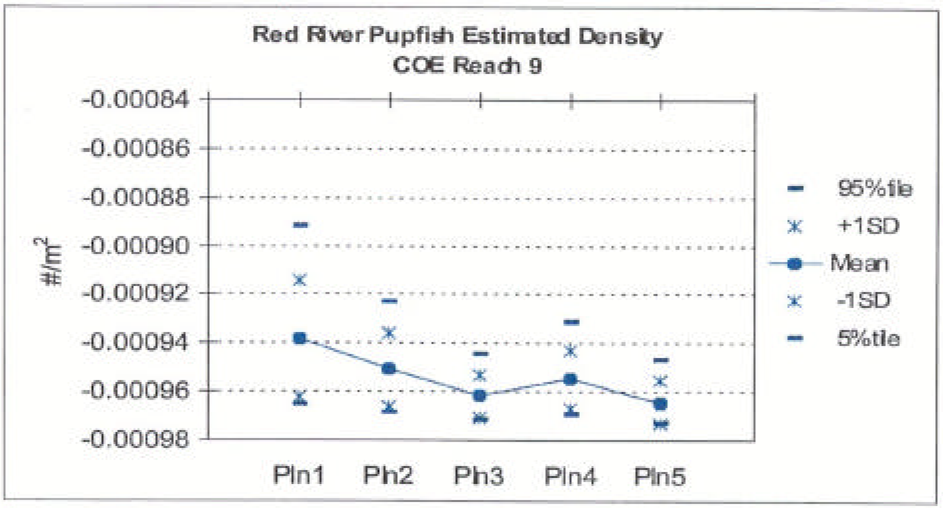
For plains killifish in Reach 5, all plans were similar (Fig. 11), and in Reach 6, values were higher for Plans 3-5, than for Plans 1 and 2. However, variability also was higher for Plans 3-5 than Plans 1 and 2, and both lowest and highest values across all plans occurred for Plan 4, and these ranged both higher and lower than those for Plans 1 and 2 (Fig. 11). In Reach 7 (exclusive of the Wichita County Irrigation District), values dropped from Plan 1 to Plan 2, and lowest values for Plans 3 and 5 dropped below those for Plan 2, while Plan 4 was similar to Plan 2 (Fig. 11). Within the Irrigation District (Reach 12), estimates under Plans 3 and 4 were higher than for Plans 1 and 2, but as for Reach 6, were more variable as well, and both high and low values ranged beyond those for Plans 1 and 2 (Fig. 11). Estimates for Reach 7 and 12 were among the lowest across all Reaches, concordant with their absence in 1998 collections.

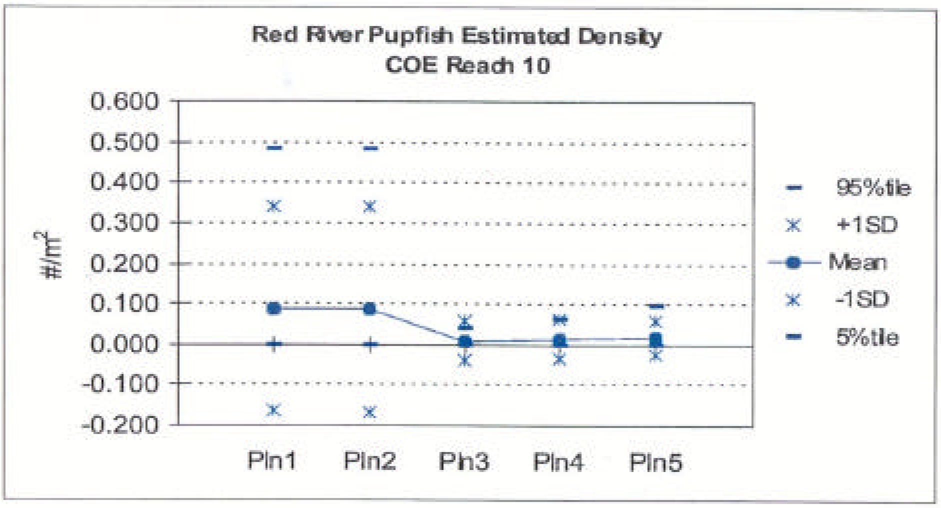
For Reaches 9 and 11, estimates of Red River pupfish density declined from Plan 1 to Plan 2 (Fig. 12). In Reach 9 low and high ranges for density dropped lower under Plan 2 than Plan 1, and still lower for Plans 3-5, than Plan 2 (Fig. 12). For Reach 10, estimates for Plans 1 and 2 were similar, but for Reach 11, estimates for Plan 2 were lower, but within range of those for Plan 1. For Reach 10 and 11, estimates for Plans 3-5 were within the ranges for Plans 1 and 2.
Estimates for plains killifish in Reaches 9 and 11 (Fig. 13) showed a similar pattern across Plans 1-5 to that for Red River Pupfish in those reaches (Fig. 12). In Reach 10, estimates were similar for Plans 1 and 2 (as for Red River pupfish), but lower ranges of estimates were much closer to lower ranges for Plans 1 and 2 (Fig. 13), than they were for Red River pupfish in that reach (Fig. 12). Means for densities of both target species for Plans 2-5 for all Reaches were between the 5th % tile and 95th % tile of Plan 1. Thus, the statistical null hypothesis of no effect was not rejected.

Discussion

Fish distributions were correlated more strongly with environmental variation among individual sites than by the variation in conditions among Reaches. Among the four assemblage types that were distinguished by their species composition, a group of 10 sites was characterized by greater densities of Red River pupfish, and a group of 3 sites had greater densities of plains killifish. In general, sites with higher densities of Red River pupfish had highest conductivities and TDS (although not at all sites within a group), and shallow runs with little riparian tree canopy. These sites were located in Reach 6, 7, and 11 (in Clay, Wichita, and King counties, respectively). Sites with highest densities of plains killifish also had high conductivities and TDS, and had higher percentages of Pasture/hay Dry land use in their watersheds, and more trees in the riparian zone. The latter conditions were more prevalent at sites in Red River tributaries in Cook county (Texas), and Love county (Oklahoma) in Reach 6, and in the South Wichita River in Knox county in Reach 11. Assemblages with salt-tolerant species rarely included species other than stress-tolerant species with generalist strategies of habitat and food use, and colonizing species such as bullhead minnows, mosquitofish, and red shiners, and thus, indicated generally harsh conditions for these sites, including intermittent flow. This is consistent with previous reported distributions for these fishes (Echelle et al. 1972).

Figure 12. Results of stochastic models of density (CPUE) for Red River pupfish in Wichita River study reaches based on 1998 field data and estimates for TDS and land use for Reaches 9-11 under COE Project Plans 1-5.





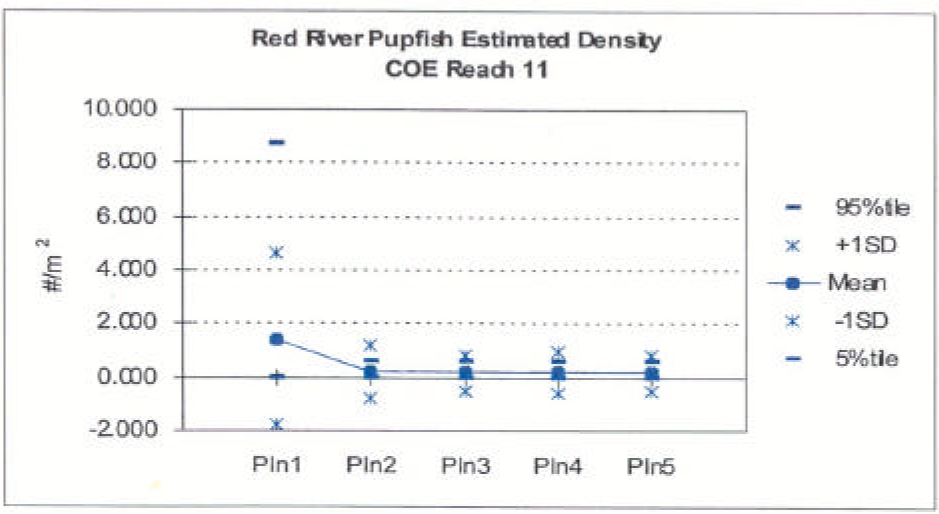
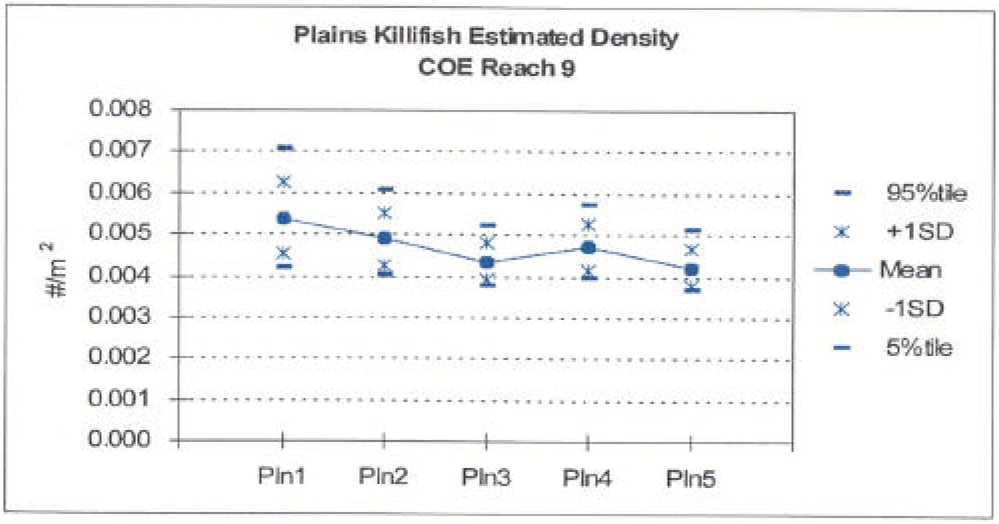
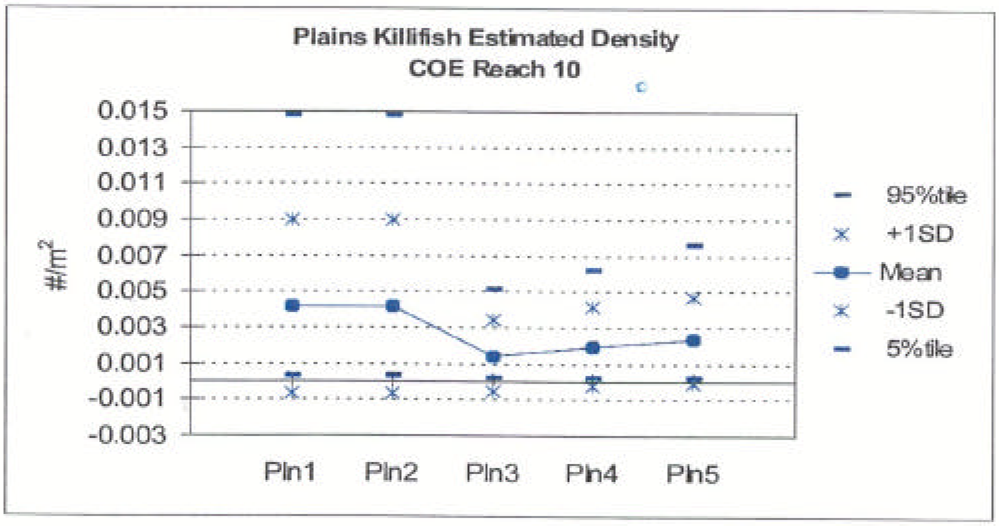
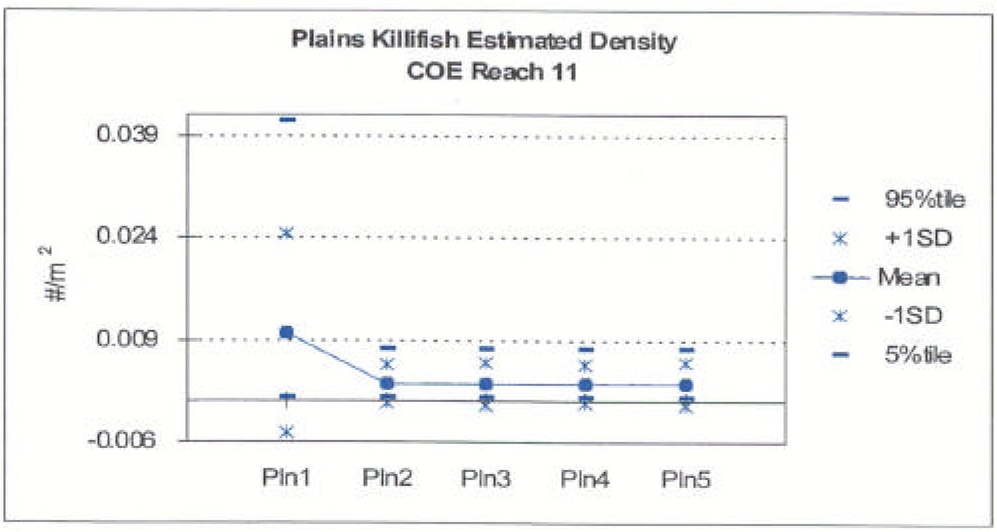


Figure 13. Results of stochastic models of density (CPUE) for plains killifish in Wichita River study reaches based on 1998 field data and estimates for TDS and land use for Reaches 9-11 under COE Project Plans 1-5.







Another assemblage group included 11 sites with high densities of green sunfish and golden shiners, as well as mosquitofish, central stonerollers, bluegill, and longear sunfish. These assemblages were broadly scattered across tributaries of the Red River (Texas and Oklahoma) that had greater areas of Pasture/hay Dry land use, or Forested Uplands within 50-m and 500-m buffers. This combination of species indicated greater likelihood of nutrient inputs from the watershed, and of more open canopy along clearings. These conditions would support primary production of attached algae, as well as secondary production of grazing minnows, invertebrates, and invertivorous fishes. These sites also had instream structure provided by fallen trees, which is favored by sunfishes. Several of these species tolerate low DO that is likely to occur when water levels fall during drought, dry riffles then isolate fishes within shrinking pools, and decomposition by bacteria of leaf litter and woody debris increases the biological oxygen demand and decreases ambient DO.

The remaining 33 sites made up a large heterogeneous group having no dominants. Instead, it included a range of species combinations from mosquitofish and red shiners, to longear sunfish, bullhead and suckermouth minnows, bluegill, and largemouth bass. These assemblages were located in the mainstem Wichita River and its tributaries, at sites with larger pools and higher percentages of shrubs in the riparian zone, or more enclosed tree canopy. This combination of species and environmental variables indicated greater likelihood of deeper water and perennial flow that maintains riffle connections among pools. Under such conditions, high production of algae and aquatic insects can occur across varying water depths, which promotes coexistence of a range of fish species that feed on invertebrates and algae, as well as larger piscivorous fishes (Matthews et al. 1986, Gelwick et al., 1997). Mosquitofish, red shiners and inland silversides, were broadly distributed with regard to values for indicators of salinity, and overlapped in their distribution with other species that had both low as well as high tolerance to increased salinity. In contrast, Red River pupfish and plains killifish were unlikely to occur at sites with low salinity, especially if several other species were likely to occur.

The stochastic models of densities under the five Project Plans low probability of risk under expanded Project Plans 3-5 that lower estimates of densities for the two salt-tolerant species in Reaches 7, 12, and 9, would fall below estimates for present-project conditions (Plan 2). Data for 1998 was not intended, nor adequate, to estimate effects of changes other than for land use and TDS. Therefore, stochastic models were run under assumptions that relationships among other environmental variables and densities of other species were constant, despite estimated effects of changes in land use and TDS. Such assumptions can only be tested with future data that might be collected as fishes and conditions are monitored across a range of environmental conditions over time (e.g., higher discharge and temporal change in salinity at fixed sites). Designed experiments or field manipulations under an adaptive strategy (Walters, 1986) of management actions, monitoring, and re-evaluation, would guide controlled, incremental revision of management plans as needed.

Several potential mechanisms for the observed fish-distribution patterns exist. This study has emphasized the role of abiotic factors (e.g., salinity and land use) to influence fish populations, in part because such effects are commonly correlated with large-scale patterns, such as along environmental gradients from harsh (drought) to benign (high rainfall) conditions (Fauch and Bramblet 1991). In the Wichita River, salinity reduction might indirectly affect competitive and predator-prey interactions between salt-tolerant species and species intolerant of harsh conditions or high salinity (e.g., bluegill, largemouth bass). In addition, lower salinity might also influence competition between salt-tolerant species and species such as mosquitofish, red shiners, and green sunfish, which tolerate harsh conditions and a narrower, but substantial, range of salinity, temperature, and DO (Echelle et al. 1972). The importance of this consideration is illustrated by the change from positive correlation between densities of red shiners and Red River pupfish at scales such as larger Reaches (Echelle, et al. 1972, and this study), to negative correlation within habitats at individual sites (Echelle et al. 1972, and this study). Our 1998 data indicated that six of 21 collections containing target species contained both species, but that plains killifish were more likely to be present with three or more other fish species (6 of 10 collections) than were Red River pupfish (1 of 5 collections). This is similar to previous observations (Echelle et al. 1972).

Ecological theories of metapopulation dynamics (subpopulations, with individuals moving among semi-isolated habitats) and effects of fragmentation on sustainability of populations are likely to apply to such systems as the Wichita-Red River (Gustafson and Gardner 1996, Holyoak and Lawler 1996, Moilanen and Hanski 1998). The roles of stochastic dynamic changes in habitat suitability and availability as related to changes in discharge and salinity were not addressed in the present study. However, such dynamics could influence sustainability of these subpopulations if their effects influenced the opportunity for particular fish species to recolonize dry reaches that could be affected by Project Plans for Chloride Control. The outcome of such effects would depend on characteristics of individual species such as whether or not they use a general range of prey, or are specialists. It also would likely depend on their tolerance to harsh intermittent flow during times when drought reduces the size of habitats, increases competition, and decreases the water quality under crowded conditions. The life-history patterns also are important because characteristics such as life expectancy, and the number of times per year, or when during a season, species reproduce will influence the growth rate of populations and their opportunity to disperse among distant habitats, or recolonize temporarily unconnected or dried reaches.

Optimal combinations of species' characteristics for particular ranges of change in abiotic variables might be estimable (Gustafson and Gardner 1996, Holyoak and Lawler 1996). For example, models for probability of movement among habitat types that depend on distance and heterogeneity or water quality in intervening habitats could be constructed using field and experimental data. Habitat use by target species and local population extinction events in individual habitats could be documented across a range of locations and distances.

A characteristic of metapopulations is the interspersion of favorable habitats unoccupied by target species among occupied habitats. Thus, individuals might migrate to alternative favorable sites from subpopulations in occupied habitats, if conditions became unfavorable in the latter. In our survey, sites with seemingly favorable conditions of salinity (among other variables) that had no target salt-tolerant species were interspersed with sites containing these species. Also sites were observed that contained populations or habitats favorable to target species, and were located outside the area of influence of the proposed Project, such as upstream of the dam sites, and on the edges or outside of the 50'-rise boundary for the evaluation area (Figs 2-4). However, until the effects of biotic and abiotic factors is better documented for fish populations in the Wichita River system over a dynamic range of conditions, estimates for present models should be interpreted with caution, and their assumptions considered under the limitations of presently available data.

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