Intensive Water Quality Monitoring at Caddo Lake, a Ramsar Wetland in Texas and Louisiana, USA

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by Roy Darville, Dwight K. Shellman Jr*. and Ray Darvillc3
Caddo Lake Institute

1. Professor of Biology at East Texas Baptist University
2. President of Caddo Lake lnstitutc (CLI)
3. Professor of Sociology and Forestry at Stephen F. Austin State University

Introduction

Caddo Lake, a complex aquatic system comprised of riverine, wetland, and lake habitats, is located in northeast Texas and northwest Louisiana. The lake has been classified as a Resource Category 1 Habitat by the U.S. Fish & Wildlife Service and in October, 1993, 6500 acres was declared the U.S.'s 13th Wetland of International Importance by the Ramsar Convention. The Ramsar Convention is an intergovernmental treaty that provides a framework for international cooperation for the conservation and management of wetland habitats. The present Caddo Lake Ramsar property is owned and managed by the Texas Parks and Wildlife Department as a wildlife management area.

Caddo Lake sits at the end of the Cypress Creek watershed which encompasses about 3000 square miles. A landscape analysis indicated that 70% of the watershed is forested, 25% is grassland, and 2% cropland (Campo, 1986). Though Caddo Lake has a surface area of over 30,000 acres, it is shallow with an average depth of one meter and maximum depth of about three meters. There are three major habitat types at Caddo Lake -- riverine, wetland, and open water. Approximately one-third of the lake is dominated by a bald cypress swamp, while the remainder is open water with interspersed bald cypress islands. The riverine habitat is represented by several major tributaries that enter the lake from the north (Kitchen Creek and James Bayou), west (Big Cypress Bayou), and south (Harrison Bayou). At the cast end of the lake is a U.S. Army Corps of Engineers constructed dam which maintains the water at 168.5 feet above. MSL. Rcccnt studies of the lake and its watershed by the Texas Parks and Wildlife Department (Campo, 1986), U.S. Fish and WiIdlife Service (Cloud, 1993) and the Caddo Lake institute (Shellman and Darvillc, 1997) suggest that the lake supports a high biodiversity. The lake is also important in the region for economic benefits gained from tourism, nature-related activitics, hunting, and fishing.

In order to conserve wetlands, the Ramsar Convention requests member states to monitor its wetlands. The Ramsar Convention does not prescribe details on how the monitoring should occur, but does provide a framework from which a plan can be developed. Water quality monitoring at Caddo Lake has been conducted over many years by a number of state and federal agencies and Caddo Lake Institute. However, the monitoring has been temporally and spatially sporadic and has only included surface water quality. The put-pose of this study was to obtain conventional water quality data on all areas of Caddo Lake, including its associated wetlands and riverine areas, during a time of the year when water quality is considered to be at its lowest. The data from this study will allow for the development of a more scientifically reliable and cost-effective water quality monitoring design.

Materials and Methods

In order to determine the overall condition of Caddo Lake, all areas of the lake, its associated wetlands, and major tributaries were sampled using a design similar to that of the Environmental Monitoring and Assessment Protocol (EMAP). EMAP was originally developed by the USEPA to provide improved information on the current status of, and long-term trends in, the condition of the nation's ecological resources. EMAP for surface waters incorporated the random selection of lakes in a specific region of the country and the intensive monitoring of those lakes. From the monitoring of these lakes, conclusions were drawn about the environmental status of lakes in the entire region (Larsen and Christie, 1993).

In the case of Caddo Lake we arc monitoring only one lake and its wetlands, so EMAP was modified to accommodate our specific needs. Using a LANDSAT base map of Caddo Lake and National Wetlands Inventory data, a geographical information system (GIS) was used to divide the lake into three habitat types: riverine, wetland, and open water (Fig 1). Within both the wetland and lake habitats, 30 equal-sized hexagons were created with each habitat type requiring a different sized hexagon. The wetland hexagons had an area of 1.05 sq km, while the lake hexagons had an area of2.22 sq km. The riverinc habitat was divided into 30 equal-sized rectangles, each with an area of 0.11 sq km. Within each habitat division, a randomly generated sampling point was derived, which resulted in a total of 90 potential monitoring sites (Fig 1). These 90 sampling sites were monitored during a 25 day period bctwccn July 14 and August 7, 1997

Twenty water quality parameters were determined at the surface and bottom of each site using standard sampling and testing protocols (Table 1). Appropriate QA/QC procedures were followed with instruments standardized daily, and appropriate blanks and standards run. Sample preservation followed APHA guidelines, which includes cooling the samples 10 4°C and in some cases preservation with acid. Lab analysis was usually completed within 48 hours of sampling, except for fecal coliform in which filtration was accomplished within 6 hours of sampling. A water quality index (WQI) was calculated for each site following procedures of Mitchell and Stapp (1996). The statistical software

SPSS was used to analyze the data statistically.

Results

Seventy-nine of the potential 90 sites were sampled during the sampling period. Eleven of the wetland sites were not sampled because they were dry. Three additional wetland sites were sampled only at the surface due to a very shallow water depth.

In general, the water was characterized by high temperatures, low dissolved oxygen, high carbon dioxide, low alkalinity, high color, high solids, low Secchi disk depth, high turbidity, high fecal coliforms, and moderate nutrient levels. Table 2 shows the mean +/- 1 srandard cieviation, minimum, maximum, and range of each parameter analyzed by site-type.

An independcnt samples two-tailed t-test was used to determine if the water column was homogeneous for each parameter (Table 3). When all sites were combined, only six parameters showed significant differences bctwccn the surface and bottom: BOD, carbon dioxide, apparent color, dissolved oxygen, pH, and temperature. When the site-types were analyzed separately, distinct differences were seen. The wetland system showed the least number of surface-bottom differences with two, while the lake showed the greatest number of surface-bottom differences with nine.

An one-w-ay ANOVA revealed that significant diffcrcnces existed among the three site-types for all parameters except hardness (Table 4). Tukey's multiple comparison test was used to detect significant differences in the parameters among the three site-types (Table 5). The wetland versus lake comparison showed the greatest number of differences (20), while the riverine versus wetland showed the least number of differences (10).

Mitchell and Stapp's water quality index was calculated for each site. The mean for all sites was 68.70, which is classified as "medium" water quality. Lake sites had the highest mean (73.89) which is classified as "good" water quality, while the riverine (66.78) and wetland sites (63.52) **were lower** and rated as "medium". The lower indices were due primarily to low dissolved oxygen levels, and high fecal colifom, turbidity, and solids.

Dissolve4 oxygen and carbon dioxide

Dissolved oxygen varied from anoxic to supersaturation conditions. Supersaturation, due to high rates of algal and macrophyte photosynthesis, occurred primarily at the shallow lake sites Anoxic conditions (< l0% oxygen saturation) occurred at 18 of the riverine sites, and 13 of both lake and wetland sites. Ten of the 19 wetland sites and four of the riverine 30 sites were also anoxic at the surface.

Carbon dioxide levels were elevated in all areas of the lake, especially at the bottom of the waler column. Both anoxic conditions and high carbon dioxide are indicative of high rates of organic matter decomposition.

Water Clarity

Water clarity at Caddo Lake was relatively low at most sites during the study. Loss of water clarity was due to both high color and high solids. Wetland sites had about twice the turbidity as the other site-types and higher color This trend was also reflected in the lower Secchi disk depth and higher solids values of the wetland sites. The best water clarity was found at the lake sites.

Turbidity in the wetland (20.6 JTU) was approximately double the turbidity of the river (9.7 JTU) and the lake (6.1 JTU). Lower turbidity in the river and lake was probably due to the lack of measurable rainfall during the study and periods to a calm or light wind.

Solids were high during the study with an overall mean of 117 mg/l. Dissolved solids composed percent of the solids. Total solids, dissolved solids, and suspended solids were highest in the wetland and lowest in the lake. Thus, the river and wetland were areas of particle sedimentation.

All three habitats were characterized by high levels of both apparent and true color. Apparent color was highest in the wetland (185 cU) and lowest in the lake (113 cU). True color, which is a measure of color due to dissolved chemicals, was similar in the wetland (.I 05 CU) and river (104 CU) and much lower in the lake (60 CU).

pH, Alkalinity, Hardness

pH varied considerably from 5.68 to 8.41. The lowest values were found at the wetland sites, whi le the highest values were found at lake sites. High pH values were probably due to a pH shift due to high rate of algal productivity in the open lake water. During times of high algal productivity, carbon dioxide levels are too low to sustain high productivity rates, therefore the algae begin to assimilate bicarbonates and carbonates for their carbon source. Thus, this high rate of photosynthesis has the effect of shifting the pH of the: water to a much higher pH level.

Caddo Lake is characterized overall by low alkalinity, which ranged from 5.0 to 78.5 with a mean of 16 mg/l. Wetland sites were characterized by the highest alkalinity values and the highest alkalinity variability. Alkalinities in this range can be problem in the future if the east Texas region continues to be subjected to acid rain.

Hardness was relatively constant at all site-types with an overall mean of68 mg/l, however values about four times higher than average (296 mg/l) were found in the upper end of James Bayou,

Nutrients,

Nutrient levels, especially phosphorus, indicate that Caddo Lake is eutrophic. Total phosphorus varied from 0.02 to 0.5 1 mg/l with an overall mean of 0.126 mg/l. Total phosphorus levels in the riverine and lake habitats were similar and much lower than those in the wetlands (0.185 mg/l). These lower concentrations could be due to a higher rate of phosphorus assimilation by phytoplankton. Reactive phosphorus showed a similar pattern to total phosphorus.

Nitrates had a mean of 1.33 mg/l at all sites and a range of 0.1 to 3.6 mg/l. Nitrates were highest in the riverine habitat (1.63 mg/l) and lowsst in the lake (1.00 mg/l) where presumably nitrates are taken up at higher rates by phytoplankton.

Fecal Coliform

Fecal coliform counts were highly variable (0 to 5000 colonies/ 100 ml) with a mean of 294. Highest values were found generally at the wetland sites with a mean of almost 600 colonies 100 ml. Conditions that lead to high fecal coliform levels in wetland include low flow, warm temperatures, and high use of wetlands by wildlife, especially birds.

Correlation of parameters

Many paramaters were found to correlated with temperature, Secchi disc depth, and the water quality index forming the greatest number of correlations with 15 (Table 6). Fecal coliform bacteria formed the fewest statistically significant correlations with 4. It is interesting to note that the water quality index correlatcd with all of the parameters used in the calculation of the index except turbidity.

Principle components analysis

To assist in the description of the parameters at the three site-types, a principle component analysis was run. Principle components analysis is a data reduction technique that groups variables along a conceptual dimension. The loading of variables on the principle component is an indication of how strongly they associate with that principle component. In this analysis six components were generated (Table 7) which explained a total of 75.8% of the variation. The first component had eight parameters with high loading values (>0.600), while the second component had four parameters with high loadings (Table 8). The first component had high loadings for true and apparent color, dissolved oxygen, ammonia, pH, Secchi disc depth, temperature, and total solids. The second component had high loadings for alkalinity, chloride, conductivity, and hardness.

Discriminant analysis

Discriminant analysis was run to determine if the three site-types could be separated by using various combinations of parameters (Fig 3). A total of68 sites were used in the discriminant analysis.

1) riverine

There was a 96.7% success in classifying riverinc sites. One site was misclassified as a wetland site. This site is a transitional site where a channelized flow emerges into a more lake-like area.

2) wetland

There was a 93.8% success of classifying wetland sites. One wetland site was misclassified as a riverine site. GIS data indicated that this area is a wetland, but in reality this site is in a old stream channel surrounded by bottomland hardwood forest.

The water quality values found at this site were more representative of a riverine habitat rather than a wetland.

3) lake
100% of these sites were classified correctly.

Due to the fact that only two sites were incorrectly classified, discriminant analysis proved to be extremely effective in correcting classifying the sites into the three site-types

Discussion

The results of this study compare favorable with previous studies of the lake by the Texas Natural Resource Conservation Commission (TNRCC 1996), U.S. EPA, and by Crowley of Stephen F. Austin State University (Table 9) Although it is realistically difficult to compare results due to different sampling techniques, laboratory analytical techniques and methods, and sampling locations and time frames, a comparison of data can be instructive. For most parameters, the data from this study very closely parallel the data from other water quality studies. The U.S. EPA conducted a eutrophication study during 1977 at Caddo Lake. The study concluded that the lake was at that time was eutrophic with high nutrients and productivity. An algal productivity study suggested that the lake was co-limited by phosphorus and nitrogen. Studies conducted by Stephen F. Austin State University in 198 1 and 1993 also suggest that eutrophication is continuing to increase at Caddo Lake.

Several of sites in this study had parameters which exceeded State of Texas Water Quality Standards or screening levels for Caddo Lake. Of particular concern, continues to be the fecal coliform levels at the lake. A U.S. Bureau of Reclamation water supply and wastewater study of 1995 concluded that sufficient fecal coliform contamination is occurring in the lake to warrant the construction of some type of sewage collection and treatment system in the many small communities that border the southwestern part of the lake (U.S. Bureau of Reclamation, 1995).

Conclusions and Future Research Directions

This project used a modification of the USEPA EMAP protocol to monitor conventional water quality parameters in a complex aquatic system of three different habitat types. Because most water quality parameters varied little from surface to bottom, in the future it will not be necessary to monitor wetland and riverine locations at both depths. In general, the data suggest that the three habitat types have relatively distinct water quality and that within each habitat type the water quality is relatively homogeneous. This allows future monitoring efforts to occur in only a few sites, but with the confidence that the site represnts the water quality in the entire habitat type.

Two key water quality issues were identified during this study: fecal coliform contamination and eutrophication. These issues will continued to be investigated by CL1 personnel. Six fixed stations have been established in the three habitat types at the lake. These will be monitored for a minimum of several years to allow for a trend analysis.

Historical data from TNRCC and CL1 have indicated that there are concerns of heavy metal and organic contamination in the lake, especially in the sediments. Currently, Caddo Lake (segment 0404) is on the state's 303(d) list under the federal clean water act, because the segment does not support the designated use. The listing was prompted due to elevated levels of barium, manganese, mercury, nickel, and zinc in the sediments and dissolved zinc in the water. Additional sampling in more locations is needed to determine the extent of the contamination in the lake as well as any trends over time.

Benthic macroinvertebrate biomonitoring needs to be done in a manner similar to the physical-chemical monitoring. Some benthic sampling has been done by CL1 but this effort has been restrictive in coverage. Additional sampling needs to be done in order to determine typical community structure in each habitat type. With additional contaminant sampling, it may be possible to correlate community structure with levels of contaminants.

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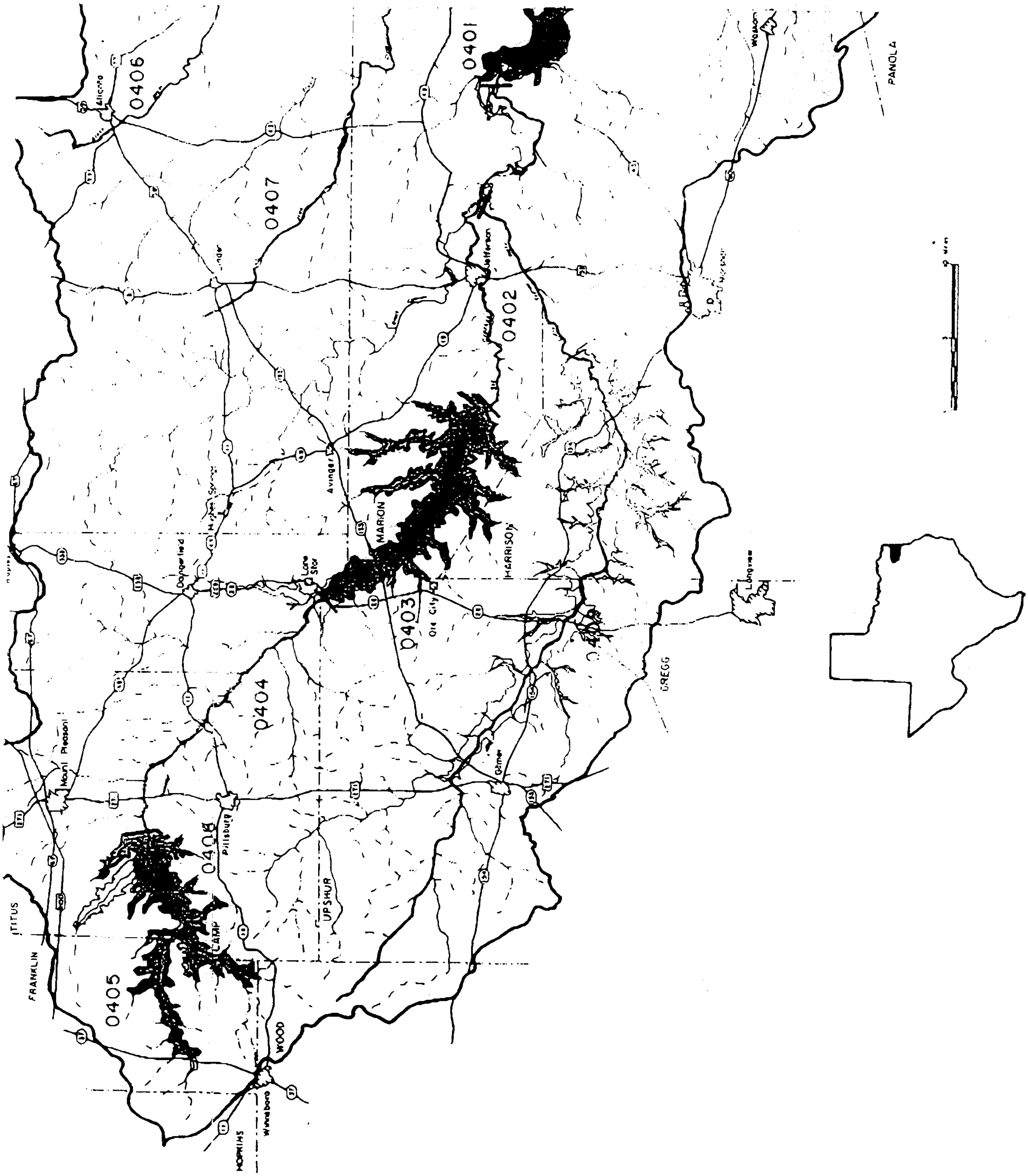
Figure 1


0401
0402
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PANOLA
MARION
HARRISON
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WOOD
FRANKLIN
TITUS
HOPKINS
Jefferson
Avinger
Lone Star
Daingerfield
Pittsburg
Mount Pleasant
Winnsboro
Gilmer
Longview
Ore City

Figure 2

Caddo Lake Sampling Scheme
Wetland, Riverine, and Lake Habitats

● Wetland ▲ Riverine ■ Lake

FIGURE 3

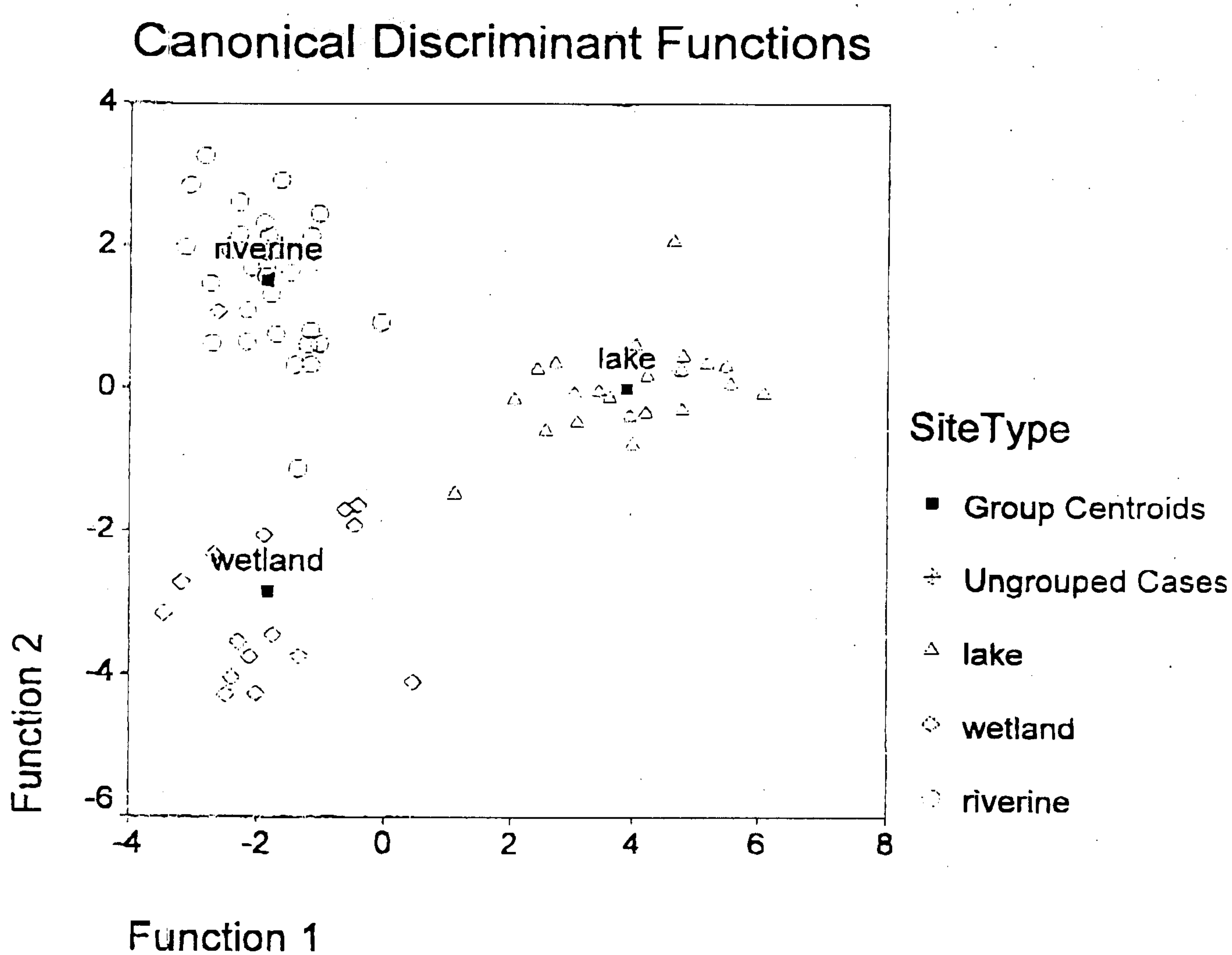
Canonical Discriminant Functions
4
2
0
-2
-4
-6
-4
-2
0
2
4
6
8
riverine
lake
wetland
Function 2
Function 1
SiteType
Group Centroids
Ungrouped Cases
lake
wetland
riverine

Table 1
Methods Used in Determination of Water Quality Parameters

Parameter	Method[1]
Alkalinity	*Standard Methods* 2320, titration to pH 4.5
BOD_5	*Standard Methods*, 5210B
Carbon dioxide	*Standard Methods*, 4500-CO_2, C
Chloride	*Standard Methods*, 4500-Cl^-, B
Color, apparent	Hach method 8025
Color, true	Hach method 8025
Conductivity	field
Depth, Secchi disk	field
Dissolved oxygen	field
Fecal coliform	*Standard Methods* 9222D, membrane filtration
Hardness	*Standard Methods* 2340
Nitrogen, ammonia	Hach method 8038
Nitrogen, nitrate	Hach method 8171
pH	field
Phosphorus, reactive	Hach method 8048
Phosphorus, total	Hach method 8190
Solids, total	*Standard Methods* 2540B, gravimetric
Solids, suspended	*Standard Methods* 2540D, gravimetric
Solids, dissolved	calculation
Temperature	field
Turbidity	Hach model 2100P, nephelometric

1. *Standard Methods* refers to *Standard Methods for the Examination of Water and Wastewater*, 18 th Ed.
field methods were done with a YSI multiparameter water quality meter, model 600 and 610D

Table 2
Descriptive Statistics for All Sites Combined

Parameter	Minimum	Maximum	Range	Mean	Standard Deviation
Alkalinity	5.0	78.5	73.5	16.49	7.73
BOD	0	8.00	8.00	1.54	1.63
Carbon dioxide	11.0	110.0	29.69	29.69	23.05
Chloride	6	130	104	22.66	12.16
Color, apparent	46	374	328	154.01	59.87
Color, true	22	306	328	87.28	41.84
Conductivity	80	603	523	128.13	54.29
Depth, secchi	0.10	1.20	1.10	0.74	0.25
Depth, total	0.10	8.00	7.90	2.81	2.35
Dissolved oxygen	0	10.81	10.81	2.82	2.96
Fecal coliform	0	5000	5000	294	681
Hardness	34	296	262	67.74	33.92
Nitrogen, ammonia	0.16	1.97	1.81	0.453	0.273
Nitrogen, nitrate	0.1	3.6	3.5	1.33	0.59
Phosphorus, reactive	0.01	0.022	0.21	0.060	0.042
Phosphorus, total	0.02	0.51	0.49	0.126	0.073
Solids, total	43	483	440	116.54	60.66
Solids, suspended	0	283	283	17.73	40.59
Solids, dissolved	0	438	438	100.93	56.36
Temperature	25.2	34.5	9.3	29.84	2.12
Turbidity	1.9	194.0	192.1	12.92	18.70
WQI	50.30	84.07	33.77	68.70	7.07

Table 3
t-Test Comparing Surface Versus Bottom Water Quality Parameters at all Sites Combined and Each Habitat Type[1]

PARAMETER	ALL SITES	RIVERINE	WETLAND	LAKE
Alkalinity				
BOD	0.001	0.001	0.008	0.001
Carbon Dioxide	0.009			0.007
Chloride				
Color, Apparent	0.019	0.048		0.001
Color, True				
Conductivity				0.024
Dissolved Oxygen	0.001	0.001		
Fecal Coliform			0.020	
Hardness				
Nitrogen, Ammonia		0.005		0.034
Nitrogen, Nitrate				
Phosphorus, Reactive				
Phosphorus, Total				
pH	0.011	0.012		0.001
Solids, Total				
Solids, Suspended				0.013
Solids, Dissolved				
Temperature	0.003	0.034		0.001
Turbidity				0.029

1. Values shown are significance values for a two-tailed t-test.

Table 4
One-Way ANOVA for All Sites Combined by Site Type

PARAMETER	F Value	Significance Level
Alkalinity	7.477	**0.001**
BOD	7.261	**0.001**
Carbon Dioxide	13.088	**0.001**
Chloride	6.343	**0.002**
Color, Apparent	32.740	**0.001**
Color, True	28.915	**0.001**
Conductivity	4.506	**0.013**
Depth, Secchi	72.61	**0.001**
Depth, Total	30.28	**0.001**
Dissolved Oxygen	32.661	**0.001**
Fecal Coliform	4.831	**0.009**
Hardness	2.808	0.064
Nitrogen, Ammonia	22.434	**0.001**
Nitrogen, Nitrate	20.407	**0.001**
Phosphorus, Reactive	14.116	**0.001**
Phosphorus, Total	18.263	**0.001**
pH	75.306	**0.001**
Solids, Total	21.500	**0.001**
Solids, Suspended	9.307	**0.001**
Solids, Dissolved	7.685	**0.001**
Temperature	23.901	**0.001**
Turbidity	3.995	**0.020**
WQI	21.916	**0.001**

Table 5

Tukey's Multiple Comparison Test for All Parameters by Site-Type [1]

Parameter	Riverine v. Wetland	Riverine v. Lake	Wetland v. Lake
Alkalinity	0.002		0.001
BOD		0.003	0.006
Carbon dioxide		0.001	0.006
Chloride		0.001	
Color, apparent		0.001	0.001
Color, true		0.001	0.001
Conductivity		0.050	0.019
Depth, Secchi	0.001	0.001	0.001
Depth, total	0.001	0.001	0.025
Dissolved oxygen		0.001	0.001
Fecal coliform	0.005		
Hardness		0.049	
Nitrogen, ammonia	0.001	0.009	0.001
Nitrogen, nitrate	0.001	0.001	0.001
Phosphorus, reactive		0.001	0.001
Phosphorus, total	0.001		0.001
pH		0.001	0.001
Solids, total		0.001	0.001
Solids, suspended			0.001
Solids, dissolved	0.006		0.001
Temperature	0.001	0.001	0.001
Turbidity	0.040		0.022

1. Probabilities of values for all comparisons where probability was less than 0.05

Table 6
Pair-wise Pearson's Correlations Between all Water Quality Parameters [1]

	Alk	Cl	CO2	Color, App	Color, True	Cond	Depth, Secchi	Depth, Total	DO	Fecal Coli	Hard	NH3	NO3	P, React	P, Total	pH	Solids, Total	Solids Susp	Solids, Diss	Temp	Turb	WQI
Alk	1	*				**	*	*		**	**						**	**	**			
Cl		1				**					**		**				**		**	**		
CO2			1	**				*	**	*		*		**	**	*	**		**			*
Color, App				1	**		**	**	**			**	**	**	**	**	*	**		**	**	**
Color, True					1		**		**			**	**	**	**	**		**		**		**
Cond						1		**			**	*				**			**	**		
Depth, Secchi							1	*	**	**		**	**	**	**	**	**	**		**		**
Depth, Total								1						**						*		
DO									1			**	**	**	**	**	**	**		**		**
Fecal Coli										1												**
Hardness											1				*		**		**	**		**
NH3												1		**	*	**	**		**	**	**	*
NO3													1			**				**		**
P, React														1	**	**	*	**				**
P, Total															1	**	*	**		*		**
pH																1	**	**		**		**
Solids, Total																	1	**	**	**	**	*
Solids, Susp																		1	**			**
Solids, Diss																			1	**	**	
Temperature																				1		**
Turb																					1	
WQI																						1

1. * = Significant at the 0.0.5 level
** = Significant at the 0.01 level

Table 7
Principle Components Analysis for All Habitat Types

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.269	26.345	26.345	5.269	26.345	26.345
2	3.345	16.727	43.073	3.345	16.727	43.073
3	1.948	9.739	52.812	1.948	9.739	52.812
4	1.859	9.294	62.106	1.859	9.294	62.106
5	1.658	8.290	70.396	1.658	8.290	70.396
6	1.071	5.356	75.752	1.071	5.356	75.752
7	.936	4.680	80.432			
8	.844	4.219	84.651			
9	.687	3.434	88.085			
10	.540	2.700	90.785			
11	.434	2.171	92.956			
12	.289	1.446	94.402			
13	.256	1.282	95.683			
14	.229	1.144	96.827			
15	.176	.878	97.704			
16	.138	.688	98.393			
17	.125	.623	99.016			
18	9.629E-02	.481	99.497			
19	6.252E-02	.313	99.810			
20	3.803E-02	.190	100.000			

Extraction Method: Principal Component Analysis.

Table 8
Principle Component Matrix with Loadings for Each Water Quality Parameter

	Component					
	1	2	3	4	5	6
ALKALIN	.195	.727	-.105	-6.63E-02	.429	-.126
CHLORIDE	.163	**.701**	6.782E-02	.387	-.253	.137
CO2	.393	-.245	.518	.317	.376	.208
COLORAPP	**.734**	-.257	.159	.120	-.285	-3.95E-02
COLORTRU	**.621**	-.242	-.298	.391	-6.53E-02	-4.80E-02
CONDUCT	.243	**.909**	4.389E-02	.145	.197	-5.60E-03
DO	**-.811**	.140	7.487E-02	5.586E-02	-.178	8.513E-03
FECALCOL	.137	.180	-.474	-.366	.224	.620
HARDNESS	.122	**.862**	-1.83E-02	.319	2.813E-02	-.259
NH4N	**.602**	-1.88E-02	.480	-.296	-.288	-.156
NO3	.359	-9.29E-02	-.448	.454	-.156	.318
P_REACT	.337	-.279	.278	.261	.564	-.212
P_TOTAL	.502	-.293	-.201	-.262	.435	1.872E-02
SUSSOLID	.419	-.116	-.212	-.122	.270	-.368
PH	**-.742**	.219	.164	-.181	.265	-9.09E-03
SECCHI	**-.791**	-3.78E-03	.295	.240	-.151	7.439E-02
TEMP	**-.744**	-.118	.183	-6.93E-02	.429	.119
TOTDEPTH	-.148	-.309	.262	.683	.246	.231
TOTSOLID	**.636**	.405	.345	-.167	7.847E-02	.334
TURBID	.434	.105	.623	-.377	-.173	.217

Extraction Method: Principal Component Analysis.
a. 6 components extracted.

Table 9
Comparison of Means from All Sites Combined with Previous Water Quality Monitoring of Caddo Lake and Standards Criteria and Screening Levels of the State of Texas

Parameter	Study				Texas Standard or Screening Level
	Present	U.S. EPA	TNRCC	Crowley	
Alkalinity, Total (mg/l)	16	15		15	
Chloride (mg/l)	23		10	19	25[1]
Chlorophyll a (µg/l)		21.3	17.9	8.63	30[2]
Color, Apparent	154			36	
Color, True	87			36	
Conductivity (µS/cm)	128	106	95	78	
D.O. (mg/l)	2.8	8.8	7.6	9.7	5.0[1]
Fecal coliform (#/100 ml)	294		4		400[1]
Ammonia (mg/l)	0.45	0.04	0.04	0.88	1.00[2]
Nitrate (mg/l)	1.33	0.035[3]	0.011[3]	0.63	1.00[2,3]
pH (SU)	6.6 (5.7-8.4)	6.8	7.3	7.0	6.0-8.5[2]
Phosphorus, Total (mg/l)	0.126	0.042	0.061		0.20[2]
Phosphorus, Reactive (mg/l)	0.060	0.010	0.024		0.10[2]
Secchi disk depth (m)	0.74	1.1		1.2	
Solids, Total (mg/l)	117				
Solids, Suspended (mg/l)	17				
Solids, Dissolved (mg/l)	101		70		100[1]
Temperature (°C)	29.8	16.8	28.7		32.22[1]
Turbidity (NTU)	13			7.2	

1. Texas Standards Criteria, based on segment 0401, Caddo Lake
2. Texas Screening Level
3. Nitrate + Nitrite (mg/l)