Effects of dechlorination of municipal wastewater effluents on fish communities in the Trinity River, Texas

Leroy J. Kleinsasser
Gordon W. Linam

River Studies Report No. 10

Resource Protection Division
Texas Parks and Wildlife Department
Austin, Texas

March 1992

EFFECTS OF DECHLORINATION OF MUNICIPAL WASTEWATER EFFLUENTS ON FISH COMMUNITIES IN THE TRINITY RIVER, TEXAS

Leroy J. Kleinsasser and Gordon W. Linam

Resource Protection Division

Texas Parks and Wildlife Department

P.O. Box 947, San Marcos, Texas 78667

ABSTRACT—Fishes were sampled upstream and downstream of two municipal wastewater treatment plants that discharge into the Trinity River, before and after dechlorination of effluents. Prior to dechlorination, chlorine toxicity was evident, with species richness significantly lower downstream of both plants compared to upstream. Rapid improvement followed dechlorination and within six months, no significant differences were detected in mean number of species or individuals between upstream and downstream collections at either plant. The results of the study make it apparent that dechlorination can allow positive and rapid improvement in stream fish communities.

Chlorination has long been the most common procedure for disinfecting municipal wastewater effluents in the United States. But while chlorine is effective in eliminating pathogens, it is also acutely toxic to fishes in low concentrations. In bioassays of chlorinated effluent, Ward and DeGraeve (1978) reported LC50 values as low as 0.040 mg/L for golden shiner (Notemigonus crysoleucas) to 0.278 mg/L for an undefined species of sunfish (Lepomis sp.). Salmonids and shiners generally exhibited the lowest tolerance to residual chlorine, while members of the sunfish family were the most tolerant (Ward and DeGraeve 1978). In field studies, Lewis et al. (1981) concluded that total residual chlorine was the most overriding toxicant in secondary sewage and Tsai (1970, 1973) observed reductions in species downstream of chlorinated sewage outfalls.

Chlorine in wastewater effluents can exist in several forms, combining with ammonia to form chloramines, or existing as a free residual in effluents containing little or no ammonia, such as those subjected to tertiary nitrification (Paller et al., 1988). Both forms are quite toxic, though free chlorine toxicity may be greater and the effect more rapid than for chloramines. In a review of literature concerning chlorine toxicity, Brungs (1973) concluded that the forms are not sufficiently different to preclude using total residual chlorine—the sum of free and combined chlorine—as a measure of toxicity.

Given the toxicity of chlorine and the historical requirement that wastewater treatment plants using chlorine for disinfection maintain a residual concentration at the outfall, acute effects were probable downstream of many municipal wastewater treatment plants. The potential for in-stream toxicity was greatest in effluent-dominated systems. In the Trinity River, Texas, Kleinsasser and Linam (1990) observed significant declines in species richness downstream from two major wastewater treatment plants and attributed them primarily to chlorine toxicity. In one instance, no fishes were collected from a site 6.9 km (4.3 miles) downstream from one of the wastewater plants. They also suggested ammonia toxicity was a contributing factor. Dean (1988) conducted in-situ toxicity tests downstream from the two plants and one other and concluded that chlorination caused significant toxicity to Trinity River fishes, sometimes five miles downstream from the outfalls.

In response to changes in permit limitations, both of the wastewater treatment plants at which

Kleinsasser and Linam (1990) observed impacts were scheduled to begin dechlorinating their effluents using sulfur dioxide December 1, 1990. Following normal chlorination, sulfur dioxide is added to dechlorinate the effluents prior to discharge into the river. Of the many chemicals available to remove chlorine from effluents, the most commonly used is sulfur dioxide (Finger et al., 1985). The intent of this study was to document whether chlorine was a significant limiting factor to fish communities downstream of the two plants by sampling fish communities upstream and downstream of each plant, before and after dechlorination and observing any response of the communities.

MATERIALS AND METHODS—The West Fork Trinity River (Figure 1) originates in southeastern Archer County and combines with the Clear, Elm, and East forks to form the mainstem. The Trinity River then flows in a southeasterly direction with ultimate drainage into the Gulf of Mexico. The Trinity River drainage basin encompasses approximately 46,620 sq. km and has a length of approximately 1130 km. The river reach evaluated in this study drains the heavily urbanized population centers of Fort Worth, Arlington, Grand Prairie, and Dallas. That area ranks much higher than the state as a whole in population density [Texas Department of Water Resources (TDWR), 1984]. The human population in the Trinity River basin was 3.2 million in 1980 and is now estimated at 4.1 million (TDWR, 1990). Impoundments and wastewater discharges play a major role in regulating flow of the Trinity River. Upstream of Fort Worth and Dallas, the river is influenced by more than 2,500 minor flow retarding structures (U.S. Army Corps of Engineers, undated) and several major reservoirs. Consequently, the volume of water entering the Trinity River downstream of the reservoirs depends upon dam releases, wastewater discharges, and runoff. During the period of May 1989 to April 1990, the Trinity River received a mean of 512 million gallons/day (MGD) of wastewater, most of it from four major wastewater treatment plants in the Fort Worth—Dallas area. The effluent was of high quality, with the biochemical oxygen demand (BOD) from the four plants averaging 2.9 mg/L during that time period.

The Fort Worth Village Creek Wastewater Treatment Plant (Figure 1) had a mean discharge of 109.3 MGD during the nine months of the study. Carbonaceous BOD and total suspended solids concentrations in the effluent both averaged 2.1 mg/L. Ammonia-nitrogen permit limits were 5 mg/L from December through May and 3 mg/L from June to November. Aquatic habitats differed somewhat upstream and downstream of the plant, mainly due to increased flow from the wastewater treatment plant and because of riprap on shorelines to prevent erosion downstream. Typically, the banks were steep, with extensive gravel riffles present upstream and downstream of the plant. Pool areas tended to have clay or silt substrates. Instream cover consisted of snags, undercut banks, and shallow bars.

During the study, the Dallas Central Wastewater Treatment Plant (Figure 1) discharged a mean of 132 MGD, with effluent concentrations of 1.7 mg/L carbonaceous BOD and 2.4 mg/L total suspended solids. Ammonia-nitrogen permit limits were 5 mg/L from December through May and 3 mg/L from June to November. Habitat within the river was similar upstream and downstream of the plant. Typically, steep banks confined the river at this site, with dropoffs common along the shoreline. Substrates consisted of hard clay to soft silt, with occasional gravel. Instream cover consisted of snags, overhanging limbs, bank undercuts, and a few shallow bars.

Fishes were sampled by boat electrofishing and seining immediately upstream and downstream of each wastewater treatment plant during three periods: Sept. 26-27 and Dec. 18-19, 1990, and May 22-23, 1991. Electrofishing was conducted with a boat-mounted, boom electrofisher producing pulsed direct current. Sampling was divided into three 5-minute periods. Fishes were enumerated and released when electrofishing was completed. Shallow-water habitats were sampled by a straight seine measuring 4.5 m in length, 1.8 m in depth, and composed of 3.1 mm delta weave mesh. Six to nine seine hauls were taken at each site. All fish from seine samples were preserved in 10% formalin and transported to the laboratory for identification and enumeration. Common and scientific names follow Robins et al. (1991). Dissolved oxygen, pH, temperature, and conductivity were measured with a Hydrolab Surveyor II. Total chlorine residual was measured in the field using the DPD Colorimetric method (Clesceri et al., 1989). Data on final effluent chlorine and ammonia concentrations and flow were obtained from the wastewater treatment plants.

Upstream and downstream electrofishing collections for each date were compared statistically with a Mann-Whitney test (Zar, 1984). Index of similarity (Odum, 1971), a measure of the degree of resemblance in species composition between two sites was calculated:

$$S = 2C/(A + B),$$

where S = index of similarity, A = number of species in sample A, B = number of species in sample B, and C = number of species common to both samples. Values can range from 0, meaning the species are entirely dissimilar, to 1.0, indicating the two sites are identical in terms of species present.

RESULTS—In the four months prior to dechlorination, monthly minima for total residual chlorine were at least 1.0 mg/L at both the Village Creek and Dallas Central plants. Maxima were greater than or in the range of 3.0 mg/L at Village Creek and somewhat lower at Dallas Central. When sampled prior to dechlorination, the in-stream total residual chlorine concentration was less than detectable upstream of each plant, but was 0.5 mg/L downstream of the Dallas Central plant and 2.0 mg/L downstream of the Village Creek plant. Post dechlorination, residual chlorine was less than detectable in the river and with few exceptions, in the plant effluents. Other water quality parameters were within ranges not detrimental to aquatic communities.

Mean number of species and individuals from electrofishing were significantly greater (α=0.05; one-tailed test) upstream of both wastewater treatment plants in the pre-dechlorination samples (Table 1). No fishes were collected by any method downstream of Village Creek during the initial sampling event (Table 2). Substantial improvement in species richness and number of individuals was observed downstream of the Village Creek in the December sample, following the onset of dechlorination. Mean number of species and individuals from electrofishing was not significantly greater upstream of Village Creek (Table 1). At Dallas Central, mean number of species were still significantly greater upstream than downstream in the December sample. In May, no significant differences were detectable in mean number of species and individuals between upstream and downstream samples at either plant. However, the mean numbers of species and individuals were greater at both downstream stations.

The cumulative number of species and individuals from electrofishing and seining followed a similar pattern as the electrofishing means in both reaches (Table 1). Prior to dechlorination, upstream samples had greater numbers of species and individuals than downstream ones. Improvement was observed downstream of both plants immediately following dechlorination and continued until total number of individuals was greater downstream of Dallas Central in the May sample. Total number of species was greater downstream of Village Creek in that sample and equal at Dallas Central. Index of similarity (Table 1) increased at both plants following dechlorination, though the rate of increase was more pronounced downstream of Village Creek.

The total absence of species in September precluded any similarity between upstream and downstream samples at Village Creek, but in December, four species were common to both (Table 2): red shiner (Cyprinella lutrensis), common carp (Cyprinus carpio), bullhead minnow (Pimephales vigilax), and inland silverside (Menidia beryllina). Species collected upstream but not downstream included gizzard shad (Dorosoma cepedianum), smallmouth buffalo (Ictiobus bubalus), blue catfish (Ictalurus furcatus), channel catfish (Ictalurus punctatus), longear sunfish (Lepomis megalotis), blacktail shiner (Cyprinella venusta), and western mosquitofish (Gambusia affinis). A white bass (Morone chrysops) was collected downstream but not upstream. The final similarity value of 0.80 at Village Creek indicated a high degree of resemblance between the upstream and downstream communities. Ten common species were observed during the May 1991 sample. Unlike the earlier collection a greater number of species was observed only downstream than exclusively upstream. Those included gizzard shad, channel catfish, white bass, and orangespotted sunfish (Lepomis humilis). Flathead catfish (Pylodictis olivaris) was the only species collected upstream, but not downstream.

At Dallas Central, the rise in similarity was not as sharp, but demonstrated a steady increase between the upstream and downstream samples. In the initial sample, seven species common to upstream and downstream collections were observed (Table 3): gizzard shad, red shiner, common carp, channel catfish, bluegill (Lepomis macrochirus), longear sunfish, and western mosquitofish. Those found upstream but not downstream were gar (Lepisosteus sp.), bullhead minnow, river carpsucker (Carpiodes carpio), smallmouth buffalo, blue catfish, flathead catfish, green sunfish (Lepomis cyanellus), largemouth bass (Micropterus salmoides), freshwater drum (Aplodinotus grunniens), blacktail shiner, inland silverside, and bigscale logperch (Percina macrolepida). White bass was collected exclusively downstream. In the second sample, seven species in common were again collected: red shiner, common carp, smallmouth buffalo, warmouth (Lepomis gulosus), longear sunfish, freshwater drum, and western mosquitofish. More species (nine) were exclusive to the upstream collection, whereas only two species were unique to the downstream station. Species only found upstream were longnose gar (Lepisosteus osseus); bullhead minnow; blue, channel, and flathead catfish; white bass; green sunfish; bluegill; and largemouth bass.

Those found exclusively downstream were gizzard shad and white crappie (*Pomoxis annularis*). In May, eight species were common to upstream-downstream collections at Dallas Central: spotted gar (*Lepisosteus oculatus*), threadfin shad (*Dorosoma petenense*), central stoneroller (*Campostoma anomalum*), red shiner, common carp, bullhead minnow, smallmouth buffalo, and western mosquitofish. Fishes found exclusively upstream were longnose gar, alligator gar (*Lepisosteus spatula*), blue catfish, inland silverside, and bluntnose darter (*Etheostoma chlorosomum*). Those observed only downstream were gizzard shad, orangespotted sunfish, longear sunfish, largemouth bass, and bigscale logperch. Though the final similarity index of 0.62 would seem to indicate some remaining dissimilarity in community composition, the upstream-downstream differences may be related to sampling variability. Statistically, the two sites were not different with respect to mean number of species and individuals and no particular trend was evident when examining the species observed exclusive to one or the other site.

DISCUSSION—The results of this study corroborate conclusions reached by Kleinsasser and Linam (1990) that chlorine was a contributing factor in fish community impacts downstream of major wastewater treatment plants in the Trinity River. Reduced species richness and numbers of individuals downstream from both plants prior to dechlorination apparently resulted from the acutely toxic total residual chlorine concentrations in the river. In-stream values measured downstream of both plants exceeded U.S. Environmental Protection Agency (USEPA) acute and chronic guidelines for chlorine, 0.019 and 0.011 mg/L, respectively (USEPA, 1985). The complete absence of fishes downstream of Village Creek was not surprising given the low base flow at the time of sampling and elevated in-stream chlorine concentrations. The total residual chlorine concentration measured downstream of Dallas Central in the pre-dechlorination sample was lower than at Village Creek, at least partially because of increased flow and dilution, but still acutely toxic. However, several species were collected in that sample, though there were few individuals and all of those came from the upper end of the sampling reach, strongly suggesting that complete mixing of the effluent had not taken place. Zillich (1972) observed a similar situation in large Michigan rivers where little lateral mixing occurred and an effluent appeared to flow along the bank downstream of an outfall for a considerable distance. Fishes may avoid those areas immediately impacted by the effluent, but are able to utilize other adjacent portions of the stream.

Dechlorination using sulfur dioxide was successful in removing acutely toxic conditions downstream of the plants based upon the absence of measurable chlorine and the improvement of the fish community downstream of the plants. These results mirror laboratory bioassays by Ward and DeGraeve (1978), who concluded that addition of sulfur dioxide was an effective way to eliminate the residual toxicity of chlorinated effluent. In their study, salmonids and shiners, which were relatively sensitive to chlorinated effluent, were able to survive in 100% dechlorinated effluent with little mortality (Ward and DeGraeve, 1978). Improvement in the fish community was rapid downstream of Village Creek. Other studies have reported similar findings. Paller et al. (1988) observed that average species number increased from two to 14 immediately downstream of an outfall only seven days after chlorination ceased.

Based upon our studies in the upper Trinity River, it is apparent that dechlorination can have a positive effect on fish communities downstream from major municipal wastewater treatment plants. Rapid improvement appears possible, particularly in instances where substantial sources for recruitment are available. Such improvement would undoubtedly be more gradual in smaller streams. Improvement might also be less dramatic in situations where other chronic water quality problems prevail. Both of the plants evaluated in this study produce high quality effluent with ammonia limitations. In all cases, however, we are convinced that dechlorination will have at least some positive benefits on stream fish communities.

ACKNOWLEDGEMENTS—The authors would like to thank the following individuals and organizations for advice and assistance: Randy Moss and Kevin Mayes, Texas Parks and Wildlife Department; and Jack Davis, Texas Natural Resource Conservation Commission (TNRCC). This study was conducted under an interagency contract with the TNRCC.

LITERATURE CITED

Brungs, W.A. 1973. Effects of residual chlorine on aquatic life. Journal of the Water Pollution Control Federation 45:2180-2193.

Clesceri L.S., A.E. Greenberg, and R.R. Trussell, (eds.). 1989. Standard methods for the examination of water and wastewater. 17th edition. American Public Health Association, Washington, D.C.

Dean, K.E. 1988. Observations on toxicity in the Trinity River resulting from chlorination of sewage treatment plant effluent. Pp. 76-82, Impacts of toxic chemicals on Trinity River fish and wildlife (R.J. Irwin, ed.). United States Fish and Wildlife Service, Fort Worth, Texas.

Finger, R.E., D. Harrington, and L.A. Paxton. 1985. Development of an on-line chlorine residual measurement and control system. Journal of the Water Pollution Control Federation 57:1068-1073.

Kleinsasser, L.J. and G.W. Linam. 1990. Water quality and fish assemblages in the Trinity River, Texas, between Fort Worth and Lake Livingston. Texas Parks and Wildlife Department, Resource Protection Division, Austin, Texas.

Lewis, W.M., R.C. Heidinger, M.H. Paller, and L.J. Wawronowicz. 1981. Effects of municipal sewage on fish communities in selected Illinois streams. Pp. 224-240, *in* The warmwater streams symposium (L.A. Krumholz, ed.). Southern Division, American Fisheries Society, Lawrence, Kansas.

Odum, E.P. 1971. Fundamentals of ecology. W.B. Saunders Company, Philadelphia, Pennsylvania.

Paller, M.H., R.C. Heidinger, and W.M. Lewis. 1988. Impact of nonchlorinated secondary and tertiary effluents on warm water fish communities. Water Resources Bulletin 24:65-76.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1991. A list of common and scientific names of fishes from the United States and Canada. Special Publication 12. American Fisheries Society, Bethesda, Maryland.

Texas Department of Water Resources. 1984. Water for Texas, Vol. 2. Report GP-4-1. Texas Department of Water Resources, Austin, Texas.

Texas Department of Water Resources. 1990. Water for Texas. Report GP-5-1. Texas Department of Water Resources, Austin, Texas.

Tsai, C. 1970. Changes in fish populations and migration in relation to increased sewage pollution in Little Patuxent River, Maryland. Chesapeake Science 11:34-41.

Tsai, C. 1973. Water quality and fish life below sewage outfalls. Transactions of the American Fisheries Society 102:281-292.

United States Army Corps of Engineers. Undated. Final regional environmental impact statement: Trinity River & tributaries. U.S. Army Corps of Engineers, Fort Worth, Texas.

United States Environmental Protection Agency. 1985. Ambient water quality criteria for chlorine. EPA report 440/5-84-030. National Technical Information Service, Springfield, Virginia.

Ward, R.W. and G.M. DeGraeve. 1978. Acute residual toxicity of several wastewater disinfectants to aquatic life. Water Resources Bulletin 14:696-709.

Zar, J.H. 1984. Biostatistical analysis. Second edition. Prentice-Hall, Inc., Edgewood Cliffs, New Jersey.

Zillich, J.A. 1972. Toxicity of combined chlorine residuals to freshwater fish. Journal of the Water Pollution Control Federation 44:212-220.

TABLE 1--Mean and total number of species and individuals (±SE) at sites upstream (=US) and downstream (=DS) of the Village Creek and Dallas Central wastewater treatment plants. Mean values are based solely on electrofishing, whereas the total number of species and individuals and index of similarity also include seine collections. Samples from the same date and location with different letters were significantly different (Mann-Whitney U; alpha=0.05).

	09/90		12/90		05/91	
	US	DS	US	DS	US	DS
Village Creek site						
Mean species #	9.0±1.15a	0.0±0.00b	3.7±0.33a	2.3±0.88a	7.0±0.58a	8.3±1.20a
Mean # of individuals	31.3±2.85a	0.0±0.00b	10.7±3.84a	5.0±1.53a	56.0±13.05a	144.0±61.85a
Total # of species	19	0	12	5	11	14
Total # of individuals	1153	0	2052	31	1542	586
Index of similarity	0.00		0.47		0.80	
Dallas Central site						
Mean species #	7.7±0.88a	1.7±1.20b	8.0±1.15a	3.7±0.67b	4.7±0.88a	5.0±1.15a
Mean # of individuals	18.0±6.03a	2.0±1.53b	13.3±2.96a	8.7±3.67a	17.0±2.00a	40.7±7.45a
Total # of species	19	8	16	9	13	13
Total # of individuals	243	11	164	137	151	224
Index of similarity	0.51		0.56		0.62	

TABLE 2. Fish species and numbers collected seining (=s) and boat electrofishing (=e) upstream (=US) and downstream (=DS) of the Village Creek Wastewater Treatment Plant. Dechlorination of effluent began Dec. 1, 1990.

Species	Common name	Gear	09/90 US	09/90 DS	12/90 US	12/90 DS	05/91 US	05/91 DS
Lepisosteus osseus	Longnose gar	e					5	2
Lepisosteus sp.	Gar species	e	3					
Dorosoma cepedianum	Gizzard shad	e			1			3
Dorosoma petenense	Threadfin shad	e	13					
Dorosoma petenense	Threadfin shad	s	15					
Cyprinella lutrensis	Red shiner	e	27		9	3	127	392
Cyprinella lutrensis	Red shiner	s	662		1955	15	1349	121
Cyprinella venusta	Blacktail shiner	s	5		1			
Cyprinus carpio	Common carp	e	5		1	10	6	8
Pimephales vigilax	Bullhead minnow	e	5			1	2	2
Pimephales vigilax	Bullhead minnow	s	329		58		27	5
Carpiodes carpio	River carpsucker	e	1					
Ictiobus bubalus	Smallmouth buffalo	e	19		11		7	4
Ictalurus furcatus	Blue catfish	e	12		7		7	8
Ictalurus punctatus	Channel catfish	e	2		1			4
Pylodictis olivaris	Flathead catfish	e	1				1	
Gambusia affinis	Western mosquitofish	s	40		4		1	24
Menidia beryllina	Inland silverside	s			1	1		
Morone chrysops	White bass	e				1		1
Morone chrysops	White bass	s	1					
Lepomis cyanellus	Green sunfish	s	1					
Lepomis gulosus	Warmouth	e	1					
Lepomis humilis	Orangespotted sunfish	s	1					4
Lepomis macrochirus	Bluegill	e	1				3	2
Lepomis megalotis	Longear sunfish	e	3		1		4	4
Lepomis megalotis	Longear sunfish	s	5		1			
Lepomis sp.	Hybrid sunfish	e			1			
Micropterus salmoides	Largemouth bass	e					1	2
Micropterus salmoides	Largemouth bass	s					2	
Aplodinotus grunniens	Freshwater drum	e	1					
Number of species			19	0	12	5	11	14
Number of individuals			1153	0	2052	31	1542	586

TABLE 3. Fish species and numbers collected seining (=s) and boat electrofishing (=e) upstream (=US) and downstream (=DS) of the Dallas Central Wastewater Treatment Plant. Dechlorination of effluent began Dec. 1, 1990.

Species	Common name	Gear	09/90		12/90		05/91	
			US	DS	US	DS	US	DS
Lepisosteus oculatus	Spotted gar	e					1	2
Lepisosteus osseus	Longnose gar	e			3		1	
Lepisosteus spatula	Alligator gar	e					1	
Lepisosteus sp.	Gar species	e	1					
Dorosoma cepedianum	Gizzard shad	e	16	1		1		3
Dorosoma petenense	Threadfin shad	e					1	1
Dorosoma petenense	Threadfin shad	s					23	12
Campostoma anomalum	Central stoneroller	s					4	5
Cyprinella lutrensis	Red shiner	e	13		1	10	34	104
Cyprinella lutrensis	Red shiner	s	56	2	44	63	35	27
Cyprinella venusta	Blacktail shiner	s	2					
Cyprinus carpio	Common carp	e	4	1	5	6	6	4
Pimephales vigilax	Bullhead minnow	e			4			1
Pimephales vigilax	Bullhead minnow	s	112		3		17	8
Carpiodes carpio	River carpsucker	e	1					
Ictiobus bubalus	Smallmouth buffalo	e	6		4	4	3	6
Ictalurus furcatus	Blue catfish	e	3		6		4	
Ictalurus punctatus	Channel catfish	e	3	2	1			
Pylodictis olivaris	Flathead catfish	e	1		1			
Gambusia affinis	Western mosquitofish	s	12	1	77	48	17	46
Menidia beryllina	Inland silverside	s	1				3	
Morone chrysops	White bass	e		1	1			
Lepomis cyanellus	Green sunfish	e			1			
Lepomis cyanellus	Green sunfish	s	1					
Lepomis gulosus	Warmouth	e			1	1		
Lepomis humilis	Orangespotted sunfish	s						1
Lepomis macrochirus	Bluegill	e	1	1	1			
Lepomis megalotis	Longear sunfish	e	2		9	2		1
Lepomis megalotis	Longear sunfish	s	4	2				
Micropterus salmoides	Largemouth bass	e	1		1			
Micropterus salmoides	Largemouth bass	s						2
Pomoxis annularis	White crappie	e				1		
Etheostoma chlorosomum	Bluntnose darter	s					1	
Percina macrolepida	Bigscale logperch	s	1					1
Aplodinotus grunniens	Freshwater drum	e	2		1	1		
Number of species			19	8	16	9	13	13
Number of individuals			243	11	164	137	151	224

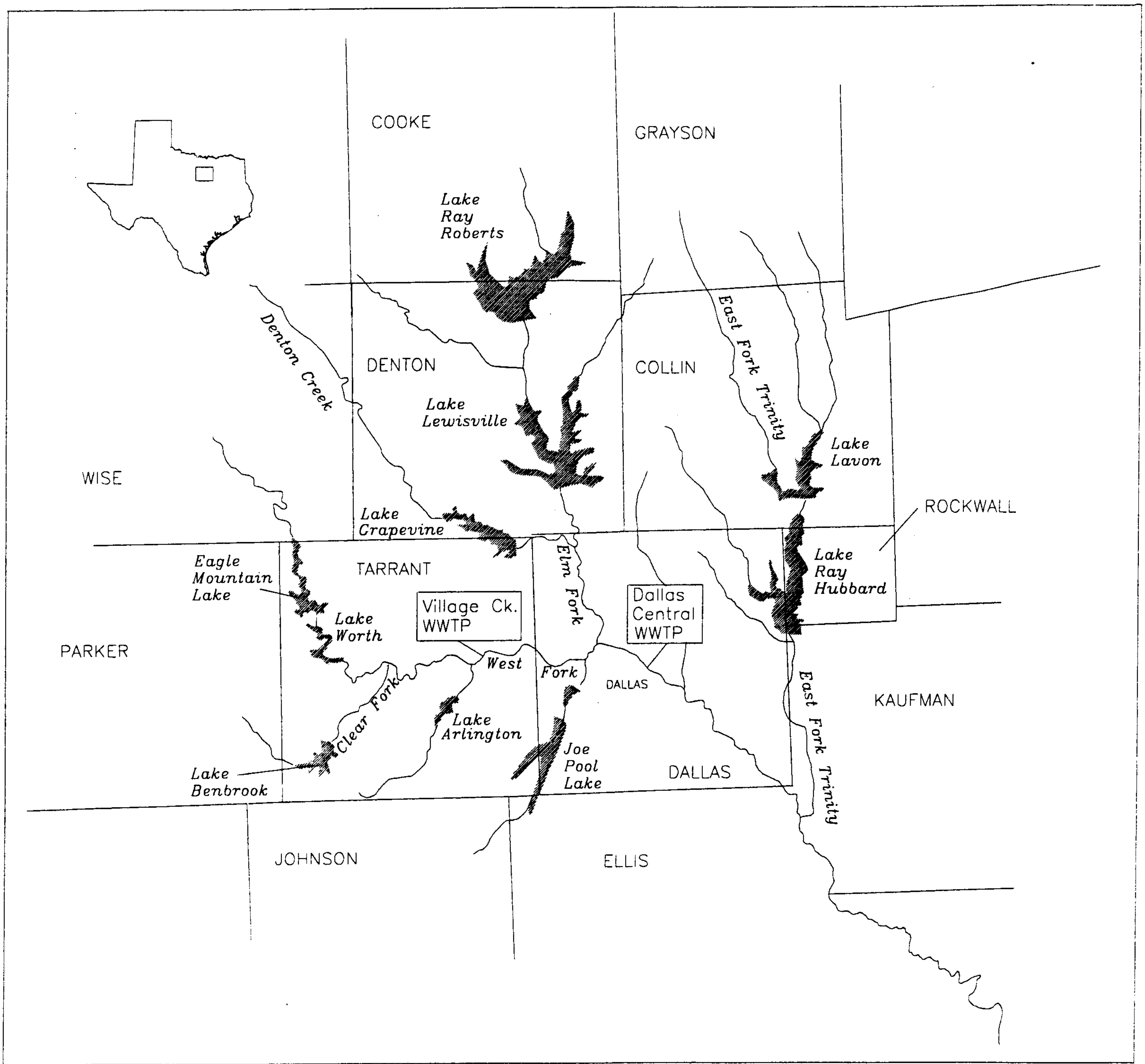

Figure 1. Map of study area. For site localities, refer to text.

TEXAS PARKS & WILDLIFE

4200 Smith School Road ▪ Austin, Texas 78744
www.tpwd.state.tx.us