Relationship Between Fishes and Water Quality in the Pecos River, Texas

Gordon W. Linam
Leroy J. Kleinsasser

River Studies Report No. 9

Resource Protection Division
Texas Parks and Wildlife Department
Austin, Texas

April 1996

Relationship Between Fishes and Water Quality in the Pecos River, Texas

GORDON W. LINAM AND LEROY J. KLEINSASSER

Resource Protection Division, Texas Parks and Wildlife Department, Austin, Texas

The Pecos River originates in the Sangre de Cristo Mountains of northern New Mexico and flows 1320 km southeast to the Rio Grande. Naturally occurring brine springs and dissolution of subsurface Permian salts in the middle reach of the river (between Fort Sumner and Roswell, New Mexico) contribute to increases in salinity (peaking in the vicinity of Girvin, Texas), as do low rainfall, high evaporation rates, and a paucity of contributing freshwater tributaries (Davis 1987). Freshwater inflow from groundwater seepage, tributaries (such as Independence Creek), and springs results in a progressive dilution of salinity in the lower reach (Davis 1987).

Three factors that have historically been known to affect the Pecos River fish fauna are streamflow, salinity (natural as well as that induced by man's activities), and agricultural and oil field pollution (Campbell 1959; Davis 1987). Two other more recently noted factors include the introduction of non-native fish species and toxic blooms of the yellow-green algae *Prymnesium parvum*. Stocking of marine sportfish species into the Pecos River, Imperial Reservoir, and Red Bluff Reservoir was common practice in the 1960's and sporadically continued through 1989 (Texas Parks and Wildlife Department 1992). Toxic algae blooms have resulted in major fish kills during 1985, 1986, and 1988 (James and De La Cruz 1989); however, toxic algae blooms may have occurred even earlier than this in the Pecos River as conditions described during a fish kill in the 1960's were similar to those observed during the documented algae blooms (Rhodes and Hubbs 1992). Several minor fish kills contributed to *P. parvum* have been documented since 1988 (C. Contreras pers. comm).

Numerous fish collections have been made in the Pecos River and Independence Creek; however, published accounts on these collections are relatively rare. Campbell *et al*. (1959) produced one of the earliest and most complete accounts of the fishes. Smith and Miller (1986) reviewed the fish fauna of the Pecos River as well as other portions of the Rio Grande Basin. Rhodes and Hubbs (1992) collected extensively in the lower reaches, but did not sample very far upstream of Iraan. Larson (1996) reported on five sampling stations over the course of the river. The Texas Memorial Musuem houses specimens from a number of collections (many of which only covered specific portions of the river and were never a part of a published document), providing the ability to make historical comparisons. These collections and their sampling dates include: Milstead and Fouquette (1941, 1949); Lindsay and Jameson (1951); Trevino *et al*. (1954); Hubbs and Springer (1954); Hillis (1979); Garrett and Marsh (1980); and Rhodes *et al*. (1987, 1988). Collections by Echelle *et al*. (1986) were consulted from Oklahoma State University.

The objectives of this study were to survey the fish community throughout the Pecos River in Texas (including Independence Creek), collect associated water quality data, and document major faunal changes by comparing recent fish collections with historical records.

Methods

Fish were sampled and water quality was measured at 16 stations in the Pecos River and Independence Creek during 12-15 October 1987 (Figure 1). Fish were collected with a straight seine (4.5 m x 1.2 m, 3.1 mm mesh), and where conditions permitted a bag seine (7.6 m x 1.2 m, 3.1 mm mesh). Length of collection at each station varied depending upon habitat types present, since all habitat types were sampled at each station. Fish were preserved in 10% formalin and identified in the laboratory (Blair *et al*. 1968; Hubbs, unpublished manuscript). Common and scientific names for fishes collected in this survey follow Robins *et al*. (1991).

Water temperature, pH, dissolved oxygen, conductivity, and salinity were measured in the field with a Hydrolab multiprobe instrument; stream discharge was measured with an electronic flow meter; and water transparency was measured with a secchi disk. Stream width was measured at the

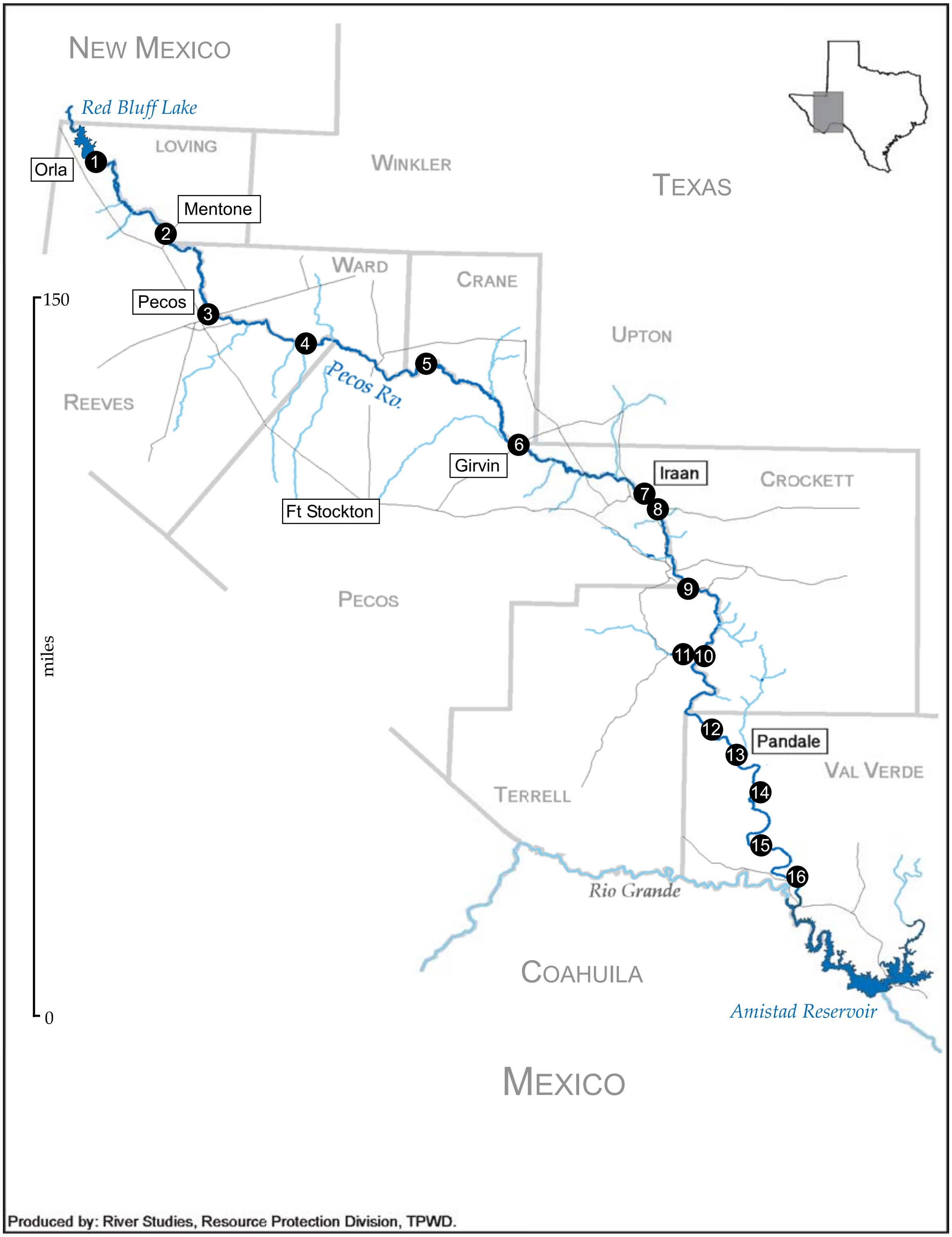

Figure 1.— Map of sampling area, see tables for site descriptions.

transect where flows were recorded and mean depth was calculated from the depths recorded during flow measurements. Water samples analyzed for the parameters listed in Table 1 were collected according to Buzan *et al.* (1987).

Results and Discussion

Physicochemical data collected in this survey are presented in Table 1. Chloride, conductivity, sulfate, sodium, calcium, and fluoride concentrations were consistent at the upper three stations, but increased in a downstream direction from FM 1776 to the station upstream of Independence Creek, though a slight dip in this steady increase was noticed at Iraan and just below Iraan. The station immediately upstream of Independence Creek had the highest values for many of the water quality parameters measured. Downstream of Independence Creek, which is a major contributor of fresher water to the system, those parameters decreased in a downstream direction. Chlorophyll *a* also steadily declined downstream of Independence Creek (which yielded the lowest concentration). Independence Creek had the lowest concentration of many of the parameters tested; however, it had the highest total alkalinity measured. Of all the parameters, only two (nitrate and bicarbonate), had their highest concentration downstream of Independence Creek. The highest silica concentration was recorded from the station just upstream of Independence Creek; however, the downstream stations averaged a higher amount than the upstream ones. All the measurements, except for conductivity and salinity, were within ranges suited for supporting a diverse freshwater fauna; however, chloride and sulfate concentrations exceeded Texas surface water quality standards at every downstream sampling station. Chloride and sulfate are recognized problems throughout the Pecos River (Texas Water Commission 1992).

Twenty-six fish species were collected in this survey (Table 2). Monthly collections (17 total) by Rhodes and Hubbs (1992), which focused on the area from Iraan to International Amistad Reservoir, yielded 30 species. Smith and Miller (1986) reported 51 species native to the Pecos River drainage and one introduced species, inland silverside (*Menidia beryllina*); though eight of those species appear restricted to the New Mexico reach of the river. Those include Rio Grande chub (*Gila pandora*), flathead chub (*Platygobio gracilis*), suckermouth minnow (*Phenacobius mirabilis*), creek chub (*Semotilus atromaculatus*), longnose dace (*Rhinichythys cataractae*), white sucker (*Catostomus commersoni*), cutthroat trout (*Oncorhynchus clarki*), and greenthroat darter (*Etheostoma lepidum*) (Hubbs *et al.* 1991; Smith and Miller 1986; Lee *et al.* 1980). Three other species occur in drainages outside of the mainstem: Leon Springs pupfish (*Cyprinodon bovinus*), Comanche Springs pupfish (*Cyprinodon elegans*), and Pecos gambusia (*Gambusia nobilis*) (Hubbs *et al.* 1991). Species that have been extirpated from the main river include American eel (*Anguilla rostrata*) and Rio Grande silvery minnow (*Hybognathus amarus*) (Hubbs *et al.* 1991; Hubbs and Echelle 1972). Bluntnose shiner (*Notropis simus*) and Pecos pupfish (*Cyprinodon pecosensis*) have been extirpated from the Texas reach of the river, but still exist in New Mexico (U.S. Fish and Wildlife Service 1992; Hubbs *et al.* 1991; Echelle *et al.* 1987). Three species collected in this survey not reported by Smith and Miller (1986) were western mosquitofish (*Gambusia affinis*), largespring gambusia (*Gambusia geiseri*), and gulf killifish (*Fundulus grandis*). Rhodes and Hubbs (1992) collected an additional one, redbreast sunfish (*Lepomis auritus*). Texas shiners (*Notropis amabilis*) were also collected even though Smith and Miller (1986) reported them as extinct from the drainage. With these modifications, the list of fishes we potentially could have collected numbered about 42 species.

Distribution of fishes appeared related to physicochemical conditions, specifically the brackishness or salinity of the water (as indicated by conductivity). Areas with high conductivity had communities dominated by seven species tolerant of wide ranges of salinity (Matthews and Hill 1977; Lee *et al.* 1980): pupfish hybrids (*Cyprinodon pecosensis* x *C. variegatus*), rainwater killifish (*Lucania parva*), gulf killifish, plains killifish (*Fundulus zebrinus*), red shiner (*Cyprinella lutrensis*), inland silverside, and western mosquitofish. These seven species comprised a mean of 71% of the species per station upstream of Independence Creek, compared to 40% at the downstream stations. The lowest percentages were found at Pandale and downstream (31, 33, 44, and 33%, respectively). These species were also numerically dominant at stations with higher conductivities. When the proportion of individuals representing salt tolerant species was regressed against conductivity, the data were described by a

Table 1. Physicochemical measurements performed on water collected from the Pecos River and Independence Creek (October 1987). Measurements recorded in the field with a hydrolab unit are designated with an asterik (*). Numbers above sample sites refer to site locations designated in Figure 1.

	1	2	3	4	5	6	7	8
	Orla (FM 652)	Mentone (SH 302)	Pecos (US 80)	FM 1776	FM 1053	Girvin (US 67)	Iraan (SH 349)	Below Iraan (low water crossing)
Date	10/14	10/14	10/14	10/13	10/13	10/13	10/12	10/12
Time	1457	1130	1810	1346	1200	1000	1530	1645
Stream Width (m)	14	13	8	9	10	7	13	6
Secchi (cm)	33	18	27	18	18	20	18	24
Average Depth (m)	0.6	0.5	0.9	-	-	0.8	0.8	0.5
Discharge (cfs)	250.2	129.0	126.8	84.9	94.1	133.8	114.7	204.9
Temperature (^oC) *	20.4	19.1	20.8	20.6	19.6	18.5	21.4	21.5
Dissolved Oxygen (mg/L) *	7.30	7.87	8.94	8.65	8.32	7.94	9.66	9.10
Total Suspended Solids (mg/L)	187	37	93	102	134	264	83	53
Volatile Suspended Solids (mg/L)	15	4	16	18	26	34	18	16
NH_3-Nitrogen (mg/L)	0.02	0.21	<0.02	<0.02	0.02	<0.02	<0.02	<0.02
Chloride (mg/L)	1446	1458	1500	1935	2435	2556	1767	2345
Chlorophyll *a* (*u*g/L)	27	18	22	21	51	58	52	28
Total Phosphorus (mg/L)	0.18	0.08	0.10	0.11	0.13	0.23	0.14	0.11
O-Phosphorus (mg/L)	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01
Conductivity (*u*mhos/cm) *	8624	8736	8848	11,172	13,272	14,224	10,080	12,936
Salinity (ppt) *	3.4	3.4	3.5	4.4	5.4	5.8	3.9	-
Total Organic Carbon (mg/L)	8	6	7	8	9	8	9	10
Pheophytin *a* (*u*g/L)	12	8	3	2	8	10	6	3
pH *	7.5	7.7	8.0	7.7	7.9	7.7	8.3	8.2
Total Alkalinity (mg/L)	114	115	110	117	116	120	117	121
NO_3-Nitrogen (mg/L)	<0.01	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sulfate (mg/L)	1327	1331	1317	1574	1755	1883	1365	1783
Silica (mg/L)	7	8	7	8	7	8	7	7
Sodium (mg/L)	924	930	933	1229	1512	1667	1159	1495
Bicarbonate (mg/L)	133	134	127	135	134	142	138	145
Calcium (mg/L)	429	424	441	484	523	540	380	511
Potassium (mg/L)	19	20	20	22	25	26	24	27
Fluoride (mg/L)	0.7	0.7	0.7	0.8	0.9	1.1	1.0	1.1
Magnesium (mg/L)	120	124	115	148	169	205	155	196
Carbonate (mg/L)	0	0	0	0	0	0	0	0

Table 1. (Continued) Physicochemical measurements performed on water collected from the Pecos River and Independence Creek (October 1987). Measurements recorded in the field with a hydrolab unit are designated with an asterik (*). Numbers above sample sites refer to site locations designated in Figure 1.

	9	10	11	12	13	14	15	16
	Sheffield (US 290)	Above Independence Creek	Independence Creek	Below Richland Canyon	Pandale	Ose Canyon	Harkell Canyon	Shumla
Date	10/13	10/13	10/13	10/14	10/14	10/15	10/15	10/15
Time	1005	1215	1315	0908	1400	1100	1500	1745
Stream Width (m)	-	-	3.6	13.6	15.2	52.4	33.6	37.9
Secchi (cm)	24	33	>122	36	36	46	61	69
Average Depth (m)	-	-	-	-	0.4	0.4	0.4	-
Discharge (cfs)	125.6	141.2	-	168.5	233.4	188.9	228.0	216.6
Temperature (^{o}C) *	20.2	20.5	24.2	19.6	20.9	19.9	22.0	21.0
Dissolved Oxygen (mg/L) *	7.10	7.58	8.33	6.93	8.90	8.70	9.60	8.90
Total Suspended Solids (mg/L)	54	45	<5	54	89	28	12	8
Volatile Suspended Solids (mg/L)	19	18	<5	15	10	3	2	3
NH_3-Nitrogen (mg/L)	0.02	0.02	<0.02	<0.02	0.02	<0.02	<0.02	<0.02
Chloride (mg/L)	3029	3843	122	2789	2003	1465	1335	1158
Chlorophyll *a* (*u*g/L)	74	86	<2	59	20	11	6	5
Total Phosphorus (mg/L)	0.07	0.07	0.01	0.06	0.06	0.03	0.03	0.03
O-Phosphorus (mg/L)	0.02	0.03	0.01	0.02	0.01	<0.01	0.01	0.01
Conductivity (*u*mhos/cm) *	12,080	14,370	1141	11,230	-	6270	5700	5090
Salinity (ppt) *	-	-	-	-	-	-	-	-
Total Organic Carbon (mg/L)	8	9	<1	7	7	3	3	3
Pheophytin *a* (*u*g/L)	10	14	3	10	3	2	<2	<2
pH *	7.8	7.9	7.9	7.8	8.0	7.7	8.2	8.1
Total Alkalinity (mg/L)	145	180	197	176	169	169	157	148
NO_3-Nitrogen (mg/L)	0.05	0.39	0.53	0.10	0.22	0.5	0.53	0.5
Sulfate (mg/L)	2080	2303	171	1763	1316	965	891	791
Silica (mg/L)	11	17	-	15	12	13	12	13
Sodium (mg/L)	1904	2295	-	1786	1236	906	828	734
Bicarbonate (mg/L)	172	207	-	210	194	198	177	176
Calcium (mg/L)	590	614	-	472	376	284	259	239
Potassium (mg/L)	30	31	-	25	18	14	13	12
Fluoride (mg/L)	1.3	1.4	-	1.3	1.1	1.0	0.9	0.9
Magnesium (mg/L)	244	301	-	232	172	139	122	107
Carbonate (mg/L)	0	0	-	0	0	0	0	0

Table 2. Fishes collected in the Pecos River and Independence Creek (October 1987). Numbers above sample sites refer to site locations designated in Figure 1.

		1	2	3	4	5	6	7	8
Taxa	Common Name	Orla (FM 652)	Mentone (SH 302)	Pecos (US 80)	FM 1776	FM 1053	Girvin (US 67)	Iraan (SH 349)	Below Iraan (low water crossing)
Dorosoma cepedianum	Gizzard shad	---	---	---	---	1	---	---	---
Astyanax mexicanus	Mexican tetra	---	---	---	7	6	---	---	2
Cyprinidae (juvenile)		---	---	---	---	---	---	---	---
Cyprinella lutrensis	Red shiner	39	10	162	85	33	96	120	1138
Cyprinella proserpina	Proserpine shiner	---	---	---	---	1	---	4	6
Cyprinella venusta	Blacktail shiner	---	---	---	---	---	---	---	---
Cyprinus carpio	Common carp	---	1	---	11	19	8	6	5
Dionda episcopa	Roundnose minnow	---	---	---	---	---	---	---	---
Macrhybopsis aestivalis	Speckled chub	---	---	---	---	---	---	---	---
Notropis amabilis	Texas shiner	---	---	---	---	---	---	---	---
Notropis braytoni	Tamaulipas shiner	---	---	---	---	---	---	---	1
Notropis jemezanus	Rio Grande shiner	---	---	---	---	---	---	---	---
Pimephales vigilax	Bullhead minnow	---	---	---	---	---	---	---	6
Moxostoma congestum	Gray redhorse	---	---	---	---	---	---	---	---
Ictalurus punctatus	Channel catfish	---	---	---	---	---	---	---	---
Cyprinodon sp.	Pupfish hybrid	3	2	30	2	168	136	26	65
Fundulus grandis	Gulf killifish	---	---	---	---	---	---	---	1
Fundulus zebrinus	Plains killifish	4	2	2	---	2	---	1	16
Lucania parva	Rainwater killifish	32	38	14	5	---	---	---	45
Gambusia affinis	Western mosquitofish	65	518	4	18	42	60	9	638
Gambusia geiseri	Largespring gambusia	---	---	---	---	---	---	---	---
Menidia beryllina	Inland silverside	16	1	3	---	2	16	5	448
Lepomis macrochirus	Bluegill	---	---	---	---	---	---	---	---
Lepomis megalotis	Longear sunfish	---	---	---	---	---	---	---	---
Micropterus salmoides	Largemouth bass	---	---	---	---	---	---	---	---
Etheostoma grahami	Rio Grande darter	---	---	---	---	---	---	---	---
Cichlasoma cyanoguttatum	Rio Grande cichlid	---	---	---	---	2	---	3	11

Table 2. (Continued) Fishes collected in the Pecos River and Independence Creek (October 1987). Numbers above sample sites refer to site locations designated in Figure 1.

Taxa	9 Sheffield (US 290)	10 Above Independence Creek	11 Independence Creek	12 Below Richland Canyon	13 Pandale	14 Ose Canyon	15 Harkell Canyon	16 Shumla
Dorosoma cepedianum	---	---	---	---	---	---	---	---
Astyanax mexicanus	---	---	40	6	30	36	17	---
Cyprinidae (juvenile)	---	---	---	---	---	12	---	---
Cyprinella lutrensis	682	106	1	147	709	351	28	---
Cyprinella proserpina	---	---	66	---	11	65	2	---
Cyprinella venusta	---	---	---	---	1	6	30	157
Cyprinus carpio	5	---	---	---	---	---	---	---
Dionda episcopa	---	---	12	---	19	46	84	---
Macrhybopsis aestivalis	---	---	---	---	1	---	---	---
Notropis amabilis	---	---	86	---	1	8	---	---
Notropis braytoni	---	4	---	---	20	1	---	8
Notropis jemezanus	---	---	---	---	---	16	---	---
Pimephales vigilax	12	---	---	1	17	273	---	5
Moxostoma congestum	---	1	---	---	---	---	---	---
Ictalurus punctatus	---	---	2	---	---	---	---	---
Cyprinodon sp.	45	---	---	1	14	47	---	---
Fundulus grandis	---	---	---	---	12	26	11	1
Fundulus zebrinus	14	---	---	---	---	---	---	---
Lucania parva	81	---	---	1	4	445	7	---
Gambusia affinis	34	1	48	31	---	76	97	116
Gambusia geiseri	---	---	64	---	---	---	---	---
Menidia beryllina	54	---	---	---	---	---	---	---
Lepomis macrochirus	---	---	---	---	---	1	---	3
Lepomis megalotis	---	---	---	1	1	---	---	---
Micropterus salmoides	---	---	1	---	---	---	---	---
Etheostoma grahami	---	---	3	---	---	---	---	---
Cichlasoma cyanoguttatum	1	1	---	---	---	9	1	---

second order regression with an r^2 of 0.76.

A salt tolerant species was the most abundant fish at all but two sites, Independence Creek and Shumla, which had the lowest conductivities in the study. Red shiners represented the greatest number of individuals of any species at eight of the 16 sampling stations, and were collected everywhere but at Shumla, where blacktail shiners (*Cyprinella venusta*) were dominant. Western mosquitofish was the most abundant species at the two uppermost sites and at Harkell Canyon, whereas the pupfish hybrid was the most abundant "species" at two consecutive stations in the upper reach, FM 1053 and Girvin. These two stations had two of the higher conductivities in the study. Past records indicate that salinity increases from the headwaters to Girvin, and then decreases downstream (Davis 1987). Therefore, the two stations where pupfish hybrids were the most abundant group have historically had the highest salinities in the river. Rainwater killifish were numerically dominant at Ose Canyon. In the fresher water of Independence Creek, Texas shiners were numerically dominant.

Two species (in addition to the four previously mentioned extirpated species) have markedly declined considering their abundance in past collections. Roundnose minnow (*Dionda episcopa*) was reported as the dominant cyprinid in most of the area downstream of Sheffield, including Independence Creek (Campbell 1959). Declines in freshwater spring flow may have contributed to it's rarity, given this species typically inhabits spring-fed streams and is seldom found in eurythermal rivers (Rhodes and Hubbs 1992; Hubbs *et al*. 1953). Gray redhorse (*Moxostoma congestum*) was also rare. Campbell (1959) reported it as common and uniformly distributed. This species was only collected at one station in our survey, immediately upstream of Independence Creek. Extensive sampling by Rhodes and Hubbs (1992) only found them in Independence Creek, and just downstream of it. Fish kill investigations revealed none between Red Bluff Reservoir and Sheffield during the 1988 fish kill; however, they were documented from Independence Creek to the riverine reach of International Amistad Reservoir during the 1985 and 1986 fish kills (J. Ralph pers. comm.). Depletion of surface water has been documented as the major cause of this species' decline in New Mexico (Sublette *et al*. 1990).

Red shiners appear to have increased in abundance, given their present dominance in areas previously reported to be dominated by roundnose minnows (Campbell 1959). Minckley (1973) indicated that within their native range, red shiners rarely become numerous in clear streams with constant flow and substantial populations of other minnow species; however, they can increase dramatically in abundance when stream flow decreases (Cross 1967). This appears to be the case here.

Fish species abundance and distribution appear to be determined by water quality factors, primarily salinity, which has increased over time (Davis 1987). This trend is likely to continue. Small to large overdrafts of groundwater have been documented in two of the upper counties bordering the Pecos River (due primarily to withdrawals for irrigation purposes), where groundwater levels have fallen as much as 150 m (Texas Department of Water Resources 1984; Brune 1981). Freshwater springs throughout the basin have gone dry in recent years, but especially hard hit has been the upper basin which is now nearly destitute of springs. Because of this, the Pecos River is now much smaller than it was formerly in the upper reach (Brune 1981). Groundwater no longer moves toward the river (in the upper reach) as in the past, but instead now moves away. As a result, the saline river water is now influencing groundwater quality which in the past had provided freshwater inflow to the river (Brune 1981). The operation of Red Bluff Reservoir will also likely continue impacting the river water quality. Except during floods, the flow of the Pecos River for a considerable distance downstream from the reservoir consists principally of releases and some seepage from the reservoir. As a result, total dissolved solids in this reach vary between 2,700 and 15,000 mg/L and exceed 7,500 mg/L 50 percent of the time (Texas Department of Water Resources 1984).

Oil and gas production are major activities in every Texas county bordering the Pecos River (Kingston 1991), and will continue to be a potential source of pollution, as will agriculture. Cotton is the major crop produced in the Pecos River watershed, with the majority of the production concentrated in the counties bordering the upper reach (Kingston 1991). Production of cotton typically includes application of arsenic based defoliants prior to harvesting. These as well as most other agriculture chemicals used in the production of crops are potential pollution sources. Livestock production is also a major number of ways through feedlot waste runoff and by decreasing the groundwater recharge through overgrazing and soil compaction (Davis 1987).

Stocking of nonindigenous species will continue to present inherent risks to the native fish fauna. Non-native species often impact native species resulting in declined numbers or their extirpation. An example is the introduction of sheepshead minnow (*Cyprinodon variegatus*) to the river and its impact on the Pecos pupfish (Echelle *et al*. 1987).

Lastly, toxic algae blooms may continue to be a recurring problem. Little is known on what conditions promote a bloom of *P. parvum*, but more than two million fish have already succumbed to its toxin (James and De La Cruz 1989). Toxin production, toxin toxicity, and the species' growth are linked to salinity and nutrient concentration (Holdway *et al*. 1978). Rainfall is likely a major factor as it affects both of these parameters. Stressful environmental conditions appear to enhance toxin formation (Shilo 1981).

Acknowledgements

Special thanks go to Texas Parks and Wildlife Department Resource Protection Division present and former staff who assisted us: J. Ralph, D. Sager, D. Palafox, C. Chandler, R. Moss, and K. Aziz. Appreciation is also extended to C. Hubbs and K. Rhodes (University of Texas), A.A. Echelle (Oklahoma State University), and D. Hendrickson (Texas Memorial Museum, University of Texas) for their discussions and sharing of information.

References

Blair, W.F., A.P. Blair, P. Brodkorb, F.R. Cagle, and G.A. Moore. 1968. Vertebrates of the United States, 2nd edition. McGraw-Hill Book Co., St. Louis, Missouri.

Brune, G. 1981. Springs of Texas. Volume I. Branch-Smith, Inc., Fort Worth, Texas.

Buzan, D., P. Roques, and B. Griffin. 1987. Texas Water Commission water quality monitoring procedures manual. Texas Water Commission, Austin, Texas.

Campbell, L. 1959. Basic survey and inventory of species present in the Pecos River of Texas. Dingell-Johnson Project F-5-R-5, Job 13. Texas Game and Fish Commission, Austin, Texas.

Cross, F.B. 1967. Handbook of fishes of Kansas. Misc. Publ. Mus. Nat. Hist. Univ. Kansas 45: 1-137.

Davis, J.R. 1987. Faunal characteristics of a saline stream in the Northern Chihuahuan Desert. Contributed Papers of the Second Symposium on Resources of the Chihuahuan Desert Region: United States and Mexico. Chihuahuan Desert Research Institute, Alpine, Texas.

Echelle, A.A., P.J. Conner, and G.R. Wilde. 1987. Status of the Pecos pupfish in Texas: a genetic analysis of the effects of hybridization with an introduced pupfish. Oklahoma State University Zoology Department, Contract no. 14-160009-1554, work order no. 7, final report, Stillwater, Oklahoma.

Holdway, P.A., R.A. Watson, and B. Moss. 1978. Aspects of the ecology of *Prymnesium parvum* (Haptophyta) and water chemistry in the Norfolk Broads, England. Freshwater Biology 8: 295-311.

Hubbs, C., R.A. Kuehne, and J.C. Ball. 1953. The fishes of the upper Guadalupe River, Texas. Texas Journal of Science 5: 216-244.

Hubbs, C. and A.A. Echelle. 1972. Endangered non-game fishes of the upper Rio Grande basin. Pages 147-167 *in* Symposium on rare and endangered wildlife of the southwestern United States. New Mexico Department of Game and Fish, Santa Fe, New Mexico.

Hubbs, C., R.J. Edwards, and G.P. Garrett. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. Texas Journal of Science 43 (supplement): 1-56.

James, T.L. and A. De La Cruz. 1989. *Pyrmnesium* [sic] *parvum* Carter (Chrysophyceae) as a suspect of mass mortalities of fish and shellfish communities in western Texas. Texas Journal of Science 41: 429-430.

Kingston, M., editor. 1991. 1992-1993 Texas almanac. A.H. Belo Corporation, Dallas, Texas.

Larson, G.L. 1996. Fish community structure in relation to water quality and habitat in the upper Pecos River, Texas. Texas Natural Resource Conservation Commission, Austin, Texas.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr., editors. 1980. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh, North Carolina.

Matthews, W.J. and L.G. Hill. 1977. Tolerance of the red shiner, *Notropis lutrensis* (Cyprinidae) to environmental parameters. Southwestern red shiner, *Notropis lutrensis* (Cyprinidae) to environmental parameters. Southwestern Naturalist 22: 89-98.

Minckley, W.L. 1973. Fishes of Arizona. Sims Printing Co., Inc., Phoenix, Arizona.

Rhodes, K. and C. Hubbs. 1992. Recovery of Pecos River fishes from a red tide fish kill. Southwestern Naturalist 37: 178-187.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1991. Common and scientific names of fishes from the United States and Canada, 5th edition. American Fisheries Society, Special Publication 20, Bethesda, Maryland.

Shilo, M. 1981. The toxic principles of *Prymnesium parvum*. Pages 37-47 *in* W.W. Carmichael, editor. The water environment: algal toxins and health. Environ. Sci. Res. Ser. 20, Plenum Press, New York, New York.

Smith, M.L. and R.R. Miller. 1986. The evolution of the Rio Grande Basin as inferred from its fish fauna. Pages 457-485 *in* C.H. Hocutt and E.O. Wiley, editors. The zoogeography of North American freshwater fishes. John Wiley and Sons, New York, New York.

Sublette, J.E., M.D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. University of New Mexico Press, Albuquerque, New Mexico.

Texas Department of Water Resources. 1984. Water for Texas, technical appendix. Volume 2. Texas Department of Water Resources, Austin, Texas.

Texas Parks and Wildlife Department. 1992. Reservoir stocking history. Texas Parks and Wildlife Department, Austin, Texas.

Texas Water Commission. 1992. Summary report: regional assessments of water quality pursuant to the Texas Clean Rivers Act (Senate Bill 818). Texas Water Commission, Austin, Texas.

U.S. Fish and Wildlife Service. 1992. Pecos bluntnose shiner recovery plan. U.S. Fish and Wildlife Service, Region 2, Albuquerque, New Mexico.