ECOLOGICAL PROFILES FOR SELECTED STREAM-DWELLING TEXAS FRESHWATER FISHES III

A Report
to
The Texas Water Development Board

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Introduction

A major goal of the Water Development Board's mission are its research, monitoring, and assessment programs designed to minimize the effects of water development projects on the affected native aquatic fauna and to maintain the quality and availability of instream habitats for the use of dependent aquatic resources. The instream flows necessary for the successful survival, growth and reproduction of affected aquatic life are a major concern. Unfortunately, instream flow data with respect to the ecological requirements of Texas riverine fishes are largely unknown. While some information can be found in the published literature, a substantial but unknown quantity of information is also present in various agencies and research museums around the state. In order to minimize the disruptions to the native fauna, quantitative and qualitative information concerning life histories, survival, growth, reproduction, and habitat utilization is needed. The purpose of this study is to develop species profiles, primarily from the literature (published and unpublished), personal observations, contributions from established researchers and museum records for various obligate or mostly obligate riverine species. This volume contributes a number of studies involving species inhabiting spring-run environments. I report on a recent survey of fishes at the San Antonio River headsprings and upper watercourse which concludes that exotic species will be long-term continuing problem. This report also provides additional species accounts for 10 of the most endangered spring-run dependent fish species in the state.

New Additions and Persistence of the Introduced Fishes of the Upper San Antonio River, Bexar County, Texas

Abstract

The fish fauna of the upper San Antonio River, Bexar Co., Texas, includes ten introduced species (*Astyanax mexicanus, Hypostomus* sp., *Poecilia reticulata, P. latipinna, Xiphophorus*

helleri, Belonesox belizanus, Cichlasoma cyanoguttatum, Oreochromis mossambicus, O. aurea and Tilapia zilli). A recent sample from this environment contained nine of the ten known introduced species, as well as two additional species (the vermiculated highfin catfish, *Pterygoplichthys disjunctivus*, and the Amazon molly, *Poecilia formosa*), that were, heretofore, not found from this location. The only fish known to have been introduced but not taken in this collection, was *Belonesox belizanus*, a species introduced in the early 1960s and not captured or observed for more than 30 years and believed to be extirpated. The introduced fishes appear to be having a substantial impact upon the native fishes of this river. Introduced species made up 61% of the species, 17% of the individuals, and 62% of the biomass of the sample. It further appears that urban influences have had a major impact upon the conditions leading to the present fish assemblage.

Introduction

The native fauna of the San Antonio River has long been subjected to biological invasions of non-native species (Hubbs et al. 1978). These introductions are suspected to have modified the fish communities by various ecological means including changes resulting from competition, predation, and interference as a result of overall similarities in habitat use and reductions from overcrowding. By 1977, six introduced fishes were found in the San Antonio River (Hubbs et al. 1978). An additional species, *Belonesox belizanus*, known to have been introduced in the previous decade, had become extirpated (Hubbs et al. 1978). By 1990, three additional fishes (*Xiphophorus helleri*, *Oreochromis aureus* and *Tilapia zilli*) had been introduced into the river, and another earlier introduction, *Poecilia reticulata,* found in 1977, was thought to have been eliminated from the system (Howells 1992). It was the purpose of this study to determine whether these observed changes had stabilized over the past decade or if the introduced forms had continued to have a substantial impact on the native fish fauna of this river.

Materials and Methods

The upper San Antonio River was sampled on 7 August 2000 using two 4.5 m small mesh common-sense minnow seines. Concentrated efforts were made in two areas. First, an approximate 150-m section was sampled in Brackenridge Park immediately east of the zoo entrance, approximately 200 m downstream from the Witte Museum. Specimens were captured in the main river and one of the ditches draining the stream system of the zoo. A second site was also sampled. This was a 150-m stretch of the river approximately 3 km downstream, in the area immediately below the abandoned low water crossing connecting River Road and Avenue A. These areas correspond to the areas most extensively sampled by Hubbs et al. (1978) in their study of the introduced fishes of the upper San Antonio River. Captured specimens were preserved and in the laboratory, identified, and the individuals of each species were counted and weighed to the nearest 0.1 g. Voucher specimens have been deposited in the Texas Natural History Collections (TNHC), The University of Texas at Austin.

Results

Eighteen species were collected (Table 1), seven native species (*Cyprinella lutrensis, Notropis amabilis, Notropis volucellus, Gambusia affinis, Micropterus salmoides, Lepomis megalotis and L. punctatus*) and eleven introduced species, including (*Astyanax mexicanus, Hypostomus* sp., *Pterygoplichthys disjunctivus, Poecilia reticulata, P. latipinna, P. formosa, Xiphophorus helleri, Cichlasoma cyanoguttatum, Oreochromis mossambicus, O. aurea* and *Tilapia zilli*). The distribution and abundance of these species are discussed below.

Notropis amabilis—Texas shiners were primarily captured at our uppermost site where they were found to be abundant inhabiting the swift waters below the low water road crossing in Brackenridge Park. Nearly all individuals possessed "flared" gills, suggesting the parasitic digenetic trematode infection (McDermott 2000) found in other fishes in nearby Comal and San Marcos spring runs and in various spring-fed streams in west Texas.

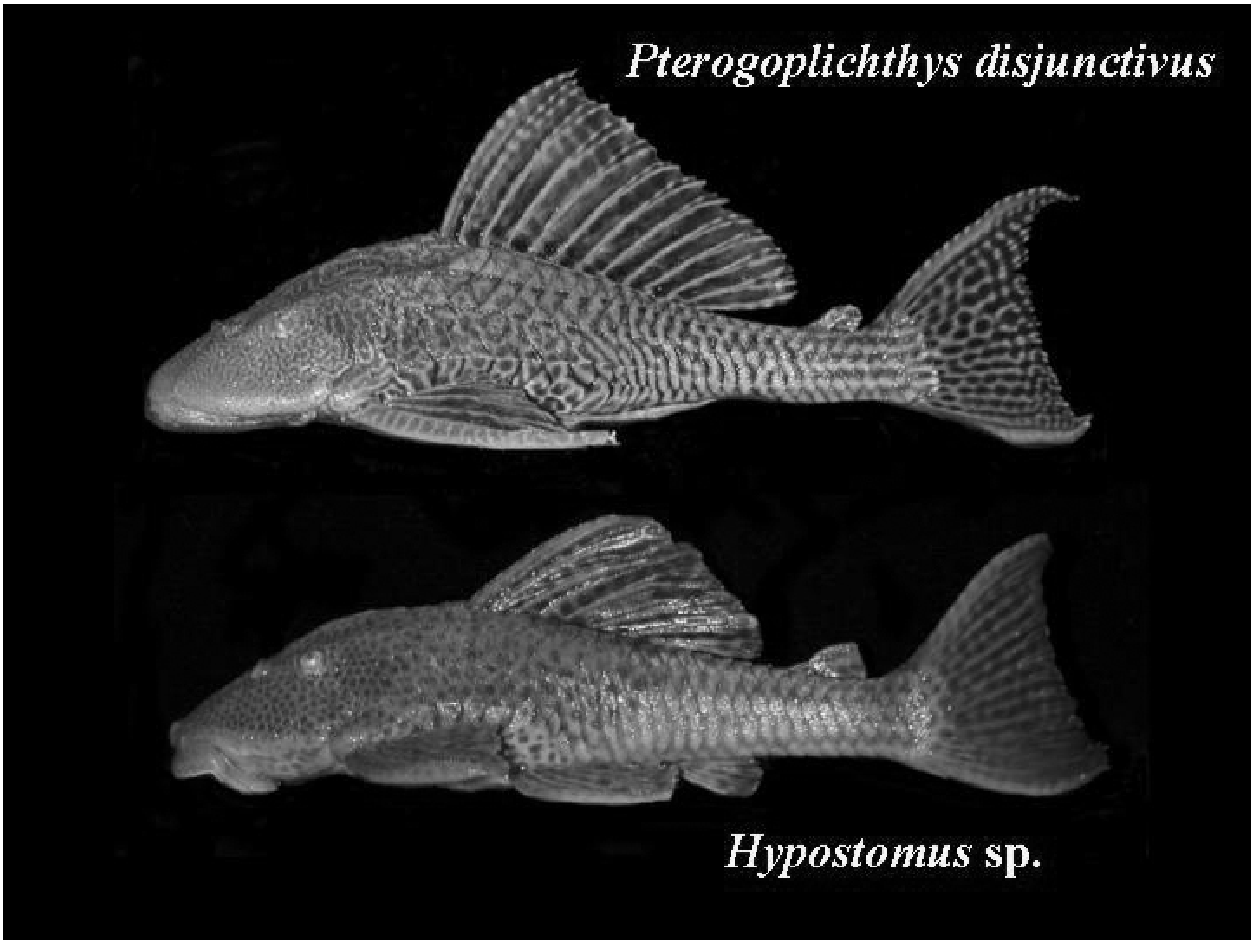
Notropis volucellus—All captured mimic shiners were taken from the lower station where they were captured over moderately flowing water over a silted sand and gravel substrate.

Cyprinella lutrensis—Red shiners were found ubiquitously throughout the study area in the main channel. This species was captured in swift as well as slow moving waters and backwaters. They were not abundant in the side channel emptying from the San Antonio Zoo.

Astyanax mexicanus—Mexican tetras were found to be abundant throughout the study area, especially in the swift moving waters in the deeper channels. Mexican tetras were first found in the San Antonio River system in 1940 (Brown 1953) and were also found to be abundant during the earlier studies by Hubbs et al. (1978) and Howells (1992).

***Hypostomus* sp.**—The armadillo del río was first introduced in 1956 into the river (Barron 1964) and has maintained a large and obvious presence since. The taxonomy of this genus remains uncertain, so species identification is not possible at this time (Page 1994). The specimen captured was found among large rocks in the swift water of the main channel below the low water road crossing in Brackenridge Park, however many individuals were observed near the concrete blocks at the other low water road crossings in the study area. Unfortunately, these individuals proved difficult to capture with seines. A local "pleco collector" along the river noted that the abundance of "plecostomus" has declined dramatically following the heavy rains and flooding that followed a severe rain event in the summer of 1998 (J. Allen, pers. comm.).

Pterygoplichthys disjunctivus—This is the first report of the loricariid vermiculated sailfin catfish from the San Antonio River. Two specimens were captured. The first was a juvenile (42 mm SL) and the other an adult (265 mm SL). These were also found in the large rocks below the low water road crossing in the park. As with *Hypostomus*, numerous individuals were observed attached to the concrete blocks downstream from the low water road crossings in the area. This species, commonly found in the aquarium trade, has been established in the Buffalo Bayou system in Houston since at least 1996 (Nico and Martin, in press) and an additional 230 mm SL specimen was captured by this author in July 2000, in Sims Bayou, part of the same Buffalo Bayou system. The first specimen taken of this species in central Texas was on 5 September 1996 in the San Marcos River by U.S. Fish and Wildlife Service biologists in their study of the springrun fauna during 1994-1996 (pers. obser.). A 15 mm SL individual was trapped in the upper spring run in the City Park area and this and the individual captured from Houston have been deposited in the TNHC museum collections. All specimens fit the description of the species given by Ludlow and Walsh (1991) and Page (1994) for individuals introduced into the Tampa, Florida area. This form is similar to individuals from the Rio Madeira drainage (Amazon River basin) of Brazil and Bolivia and commonly raised in Florida tropical fish farms (Page 1994). A variety of sailfin armored catfishes, *Pterygoplichthys*, have been reported from Florida, Hawaii, South Carolina, and now Texas (Fuller et al. 1999). The two species of Loricariidae presently found in Texas waters are easily distinguished. *Hypostomus* sp. has a much more spotted color pattern, has a lighter brown background color and possesses one spine and seven soft rays on its dorsal fin. *Pterygoplichthys disjunctivus*, in contrast, is heavily vermiculated with an overall deep chestnut brown background color and has a very high and long dorsal fin with one spine and 12 soft rays. In adults, the spotted versus vermiculated pattern is most distinctive on the belly of these two species.



Poecilia reticulata—Guppies were only found in the side channel emptying from the zoo. They were not abundant in our collections; we took only five individuals. This is in contrast to the collections of Hubbs et al. (1978) where hundreds of guppies were taken in the same place as well as close by in the main river channel. It is thought that guppies were introduced in the mid-1970s, because there are no records of these before the Hubbs et al. (1978) collections of this very obvious species. It is interesting that no guppies were taken by the TPWD collections in the area during 1985-1990 (Howells 1992). This may point to the gradual decline of the species in the system or to multiple introductions and exterpations as has occurred in Arizona and Florida where populations do not appear to be self-sustaining (Courtenay and Meffe 1989).

Poecilia latipinna—First introduced in 1939 from Florida aquarium stocks (Brown 1953), sailfin mollies were found throughout the upper and lower sites. They were most commonly encountered in quiet backwaters and in slow moving portions of the river.

Poecilia formosa—Amazon mollies were found in nearly equal numbers to their sexual host, *P. latipinna*, and were very abundant in a shallow backwater environment at the downstream collection site. This species, native to extreme south Texas, was introduced into the lower Nueces River basin by 1964 (Martin 1964), in the San Antonio drainage (in Braunig Reservoir, 40 km to the southeast of San Antonio) by 1977 (Hubbs et al. 1978), and in the San Antonio River proper at the IH-37 crossing south of San Antonio in 1978 (Edwards 1980). This is the first report of this species being collected in Brackenridge Park. The present distribution of the Amazon molly might involve an upstream migration in the last 20 years rather than a more recent introduction. Another population has long existed in the San Marcos River (Hubbs et al. 1991).

Xiphophorus helleri—Swordtails were likely introduced into the San Antonio River during the mid-1980s as none had been obtained prior to that time (Howells 1992). A single individual of this species was obtained in the side channel coming from the zoo next to the sparse vegetation in this location.

Gambusia affinis—The western mosquitofish is the only member of the family Poeciliidae that is native to the river and was the most abundant species captured. It was especially abundant at the interface between the side channel coming from the zoo and the main channel of the river. It was typically found in quiet areas near the sides of the stream.

Micropterus salmoides—Largemouth bass were captured at both upstream and downstream stations. Larger bass inhabited deeper pools and juveniles were captured next to aquatic vegetation.

Lepomis megalotis—Limited numbers of longear sunfish were found associated with the largemouth bass in the pool areas in the upper segment, however, none was captured at the lower segment.

Lepomis punctatus—One spotted sunfish was taken in the main channel of the upper site below a low water bridge crossing at the uppermost collection locality.

Cichlasoma cyanoguttatum—Rio Grande cichlids were captured throughout the study area. Young were taken near the shoreline in the main river and in the channel draining the zoo. Larger individuals were taken in deeper pools. This species was introduced into the San Antonio River in 1929, or shortly thereafter, from stocks taken from the Mission, Texas area in 1928 and raised at the federal fish hatchery in San Marcos (Brown 1953, Hubbs et al. 1978).

Oreochromis mossambicus—Mossambique tilapia were captured abundantly in the upper site in nearly all habitats sampled. In terms of biomass, this species dominated all others at this site. Although 135 individuals were captured, many more could easily have been obtained. The largest adults were observed defending redds in the main channel as well as the side channel leading from the zoo. Mossambique tilapia were first reported from the San Antonio River in the late 1950s, a result of fish escaping from the channel running through the zoo (Brown 1961). The large number of individuals captured in the present sample is in stark contrast to the relatively small number captured in the earlier 1977 collection by Hubbs et al. (1978).

Oreochromis aureus—Blue tilapia were captured in much smaller numbers than Mossambique tilapia. Both species appeared in the same samples and no evidence was found of any habitat partitioning between these two species. Although blue tilapia were known from the San Antonio drainage (in Braunig Reservoir) in 1977, none had been obtained in the river proper prior to the late 1980s when they were introduced into the zoo (Howells 1991). Hybridization between blue and Mossambique tilapias is suspected and has occurred elsewhere in central Texas (Howells 1991). A biochemical examination of genetic contamination in these stocks could better resolve the extent that this is already happening.

Tilapia zilli—All redbelly tilapia were captured in the side channel leading from the zoo. They were captured over very silty substrates and none were observed or captured in the main channel. This species, not found in the 1977 sample (Hubbs et al. 1978), was first recorded from the San Antonio River in 1978 (Hubbs 1982) and they appear to have maintained essentially their same distribution within the river since that time.

Discussion

More than 20 years ago, 35% of the 17 species that were taken in the upper San Antonio River were introduced species. Hubbs et al. (1978) considered this a substantial concern and urged care to prevent greater damage to the native fauna of this stream. Introduced species now make up 61% of the species, 17% of the individuals, and 62% of the biomass in the upper San Antonio River indicating that even greater alterations to the aquatic community have occurred. Species captured by Hubbs et al. (1978) that were not captured in our collections were *Ictalurus natalis, Lepomis gulosus, L. cyanellus, and L. macrochirus*, all native species, but none of these species was considered especially abundant during the earlier study. Other changes in relative abundance since the 1977 sample include fewer *A. mexicanus*, *Hypostomus* sp., *P. reticulata*, *L. megalotis*, and *C. cyanoguttatum* in the current sample. Much greater relative abundances of *G. affinis* and both *Oreochromis* species were found in the current samples.

While the decline in *C. cyanoguttatum* due to the Mozambique tilapia was predicted by Hubbs et al. (1978), the extremely high numbers of the latter species may now also be affecting other species. Several hundred actively guarded and recently abandoned tilapia nests were observed throughout the study area. It may be that the large numbers of breeding tilapia and their nesting activity utilize much of the desirable breeding habitat in the upper river because both the cichlids and centrarchids are nest builders and use similar habitats for breeding. In addition, both Mexican tetras and the tilapias are generalized feeders, thus high numbers of tilapia may decrease the amount of food available for the tetras. Regardless of the changes in abundance since earlier studies, only one species is thought to have been an unsuccessful introduction. The pike gambusia, *Belonesox belizanus,* was introduced into the San Antonio River in the early 1960s (Barron 1964), however it had disappeared prior to the mid-1970s (Hubbs et al. 1978) and has not been collected since.

Other non-native organisms, such as the snails, *Marisa cornuareitis, Melanoides tuberculata*, and *Thiara grandifera,* are also showing similar increases and persistence as the fishes in this system. While their impact on the fish communities has been incompletely studied, there is little question that introduced species are having an impact on the fishes in this environment and present a pervasive problem that cuts across taxonomic boundaries.

Introduced organisms not only disrupt native interactions brought about through common evolutionary histories, but also serve as source populations for their further spread into new areas creating even greater problems for the indigenous faunas. It is clear that aquarists are helping to spread these species into additional sites (J. Allen and J. Heflin, pers. comm.), especially the armored catfishes. The high success rate of these introductions into this particular ecosystem may be as a result of the artificial pumping of groundwater that maintains relatively constant water levels for the river walk area in the downtown business district, but also maintains relatively stable water temperatures and flows in the headwater area. Urban influences, including bank stabilization, storm drain and street runoff, and the zoo's maintenance of fish feeding machines, adding many nutrients to the canal leading through the zoo, contribute to the degradation of the upper San Antonio River habitats decreasing suitable habitats for the native fishes.

It appears that the problems brought by introduced species may be most acute in spring environments where the stability of water conditions, especially water temperatures, allow these introduced species to prosper. It is also in these same environments that many of the most unique and endangered species of the state are found. Much more care appears to be necessary to prevent further stresses on these species and to provide proper management of these environments for our native species.

Table 1. Introduced and native fishes captured in the upper San Antonio River, Texas. The date of first introduction, if known, is indicated and the presence of each species during various historical collections reported by Hubbs et al. (1978) and Howells (1992) is shown. The numbers reported for this study are the percent contribution of each species by number and biomass (in parenthesis) in the collected sample.

Species	Approximate Date of Introduction (citation)	1977	1985-90	This Study 2000
Introduced Species				
Astyanax mexicanus	1940 (Brown 1953)	X	X	1.9% (7.4%)
Belinesox belizanus	early-1960s (Barron 1964)			
Poecilia reticulata	1970s? (Hubbs 1978)	X		0.3% (0.1%)
Poecilia latipinna	1939 (Brown 1953)	X	X	2.5% (2.5%)
Poecilia formosa	late-1990s? (this study)			2.7% (3.2%)
Xiphophorus helleri	mid-1980s (Howells 1992)		X	0.1% (0.03%)
Hypostomus sp.	1956 (Barron 1964)	X	X	0.1% (3.6%)
Pterygoplichthys disjunctivus	mid-1990s? (this study)			0.1% (17.7%)
Cichlasoma cyanoguttatum	1929 (Brown 1953)	X	X	1.5% (0.6%)
Oreochromis mossambicus	late-1950s (Brown 1961)	X	X	6.8% (23.2%)
Oreochromis aureus	late-1980s (Howells 1991)		X	1.2% (3.1%)
Tilapia zilli	1978 (Hubbs 1982)		X	0.3% (0.4%)
Native Species				
Notropis amabilis				8.7% (5.6%)
Notropis volucellus				0.8% (0.6%)
Cyprinella lutrensis				4.7% (6.2%)
Gambusia affinis				68.0% (21.4%)
Micropterus salmoides				0.2% (2.4%)
Lepomis megalotis				0.3% (1.8%)
Lepomis punctatus				0.1% (0.2%)
N Captured (Mass in g)				1982 (2121.0 g)

Species Accounts of Selected Obligate Riverine Species

The following species accounts are for a number of species that are among the most imperiled species of the state. Each are commonly found in environments with a significant spring-flow component. All accounts have been compiled as a group effort with Dr. Clark Hubbs (Section of Integrative Biology, The University of Texas at Austin and Dr. Gary P. Garrett (Heart of the Hills Research Station, Texas Parks and Wildlife Department) in a style consistent with the format used in the “Threatened fishes of the world” series in the journal, *Environmental Biology of Fishes*.

Dionda diaboli **Hubbs and Brown 1956 (Cyprinidae)**

Common Name: Devils River minnow. **Conservation Status:** *Dionda diaboli* is listed as federally threatened by the United States (U.S. Fish and Wildlife Service 1999) and threatened by the state of Texas. **Identification:** *Dionda diaboli* can be recognized by darkly outlined scales above the lateral stripe, giving a cross-hatched appearance. They also have a black spot on the caudal fin base that is often wedge-shaped, a black stripe along their sides, through the eye and onto the snout, and double dashes along the lateral line. Adults are typically 30 to 40 mm SL. Other aspects of the morphology (Hubbs and Brown 1956), allozymes (Mayden et al. 1992) and genome size (Gold et al. 1992) of *D. diaboli* also have been documented. Photo by G. Sneegas. **Distribution:** Members of the genus *Dionda* are specialized for living in spring-fed, flowing-waters and are found primarily in Texas and Mexico. The Devils River minnow, *D. diaboli*, and its congener, the manatial roundnose shiner, *D. argentosa*, constitute one of several species pairs within the genus that apparently evolved allopatrically and whose current sympatry is a result of the paleohydrology of the region (Mayden et al. 1992). The type locality of *D. diaboli* is Baker's Crossing in the Devils River, Val Verde County, Texas (Hubbs and Brown 1956). This species is known to occur in Texas in the Devils River, San Felipe Creek and Sycamore Creek, Val Verde County. It historically occurred in Las Moras Creek, Kinney County, but has been extirpated from this locality (Smith and Miller 1986; Garrett et al. 1992). There are also historic records of occurrence in two small streams in Coahuila, Mexico, the Río San Carlos and Río Sabinas. Because no collections have been made there since the early 1970s, their current status in Mexico is unknown but, at best they are thought to be rare (Miller 1978). **Abundance:** The Devils River minnow has a spotty distribution within its range. At various times it has been relatively abundant (Hubbs and Brown 1956, Harrell 1978), yet at other times the species has been exceedingly rare (Garrett et al. 1992). **Habitat and Ecology:** Little is known of the life history of the species and habitat specificity is not known. They are often found in association with spring outflows and adjacent to aquatic macrophytes and it may be that they inhabit a microhabitat associated with the interface between spring runs and the river (Hubbs and Garrett 1990). **Reproduction:** The species is likely to spawn in the spring with non-adhesive and demersal eggs, similar to traits reported for *D. serena* (Hubbs 1951). **Threats:** Populations of *D. diaboli* appear to have become reduced in number and size in recent history (Garrett et al. 1992). Reasons for this decline are not known, although habitat loss has occurred through minimal flows in Sycamore Creek and inundation of the lower Devils River by Amistad Reservoir. Remaining populations are potentially threatened by a) loss of habitat through reduction in spring flows, b) reduction in water quality and c) predation and competition with exotic species. However, since little is known of the life history requirements or the ecological interactions of the Devils River minnow, it is difficult to properly assess threats or fully implement recovery actions. **Conservation Action:** A Conservation Agreement was developed in 1998 among the

Texas Parks and Wildlife Department, the City of Del Rio and the U.S. Fish and Wildlife Service and is designed to foster research to "eliminate or significantly reduce the probability that potential threats to the minnow will actually harm this species and to recover populations of the minnow to viable levels." A critical subset of the range of *D. diaboli* is now protected by lands owned by the Texas Parks and Wildlife Department and the Nature Conservancy of Texas.

Conservation Recommendation: The conservation actions and recommendations listed in the Conservation Agreement should be fully implemented in order to ensure the survival of this species. Further research on the ecological requirements of this species is especially warranted.

***Cyprinodon bovinus* Baird and Girard 1853 (Cyprinodontidae)**

Common Name: Leon Springs pupfish. **Conservation Status:** *Cyprinodon bovinus* is listed as federally endangered by the United States (U.S. Fish and Wildlife Service 1980) and endangered by the state of Texas. **Identification:** *Cyprinodon bovinus* have 25 or fewer lateral scales with a scaled abdomen. Mature males possess a caudal fin bar of moderate width and typically lack vertical bars on the body. The barring pattern of females is typically not continuous, but broken ventrolaterally (Echelle and Miller 1974). Photo by G. Sneegas. **Distribution:** Leon Springs pupfish were first collected in 1851 by the U.S. and Mexican Boundary Survey at Leon Springs (Baird and Girard 1853). Leon Springs no longer exists due to impounding, inundation and groundwater pumping (Hubbs 1980). In 1965, W.L. Minckley and W.E. Barbour collected *C. bovinus* in Diamond-Y Spring. They were subsequently found to occur downstream throughout Diamond-Y Draw (=Leon Creek), a small (8-10 km) stream that is a flood tributary of the Pecos River and approximately 15 km downstream from the original Leon Springs (Echelle and Miller 1974). **Abundance:** *Cyprinodon bovinus* was extirpated from Leon Springs as early as 1938 (Hubbs 1980) and presumed extinct (Hubbs 1957). The population size in Diamond-Y Draw is estimated to be fewer than 10,000 individuals (A. A. Echelle, pers. comm.). **Habitat and Ecology:** In the early 1900s Leon Springs flowed at approximately 20 cfs, but heavy groundwater pumping reduced the flow to 0 by 1962 (Echelle and Miller 1974). Today the primary water source for the creek is Diamond-Y Spring (Echelle and Miller 1974). Individuals live about 20-23 months and have a generalist diet consisting of such items as diatoms, marl, algae and invertebrates. (Kennedy 1977). “Pit digging” behavior seems to be for locating food (Minckley and Arnold 1969), especially in *C. bovinus* males (Kennedy 1977). **Reproduction:** Sexual maturity occurs at approximately 30 mm SL (Kennedy 1977). Spawning occurs almost year around, but peaks in July (Kennedy 1977). Peak spawning temperature is 24^{o} to 29^{o} C which results in two primary spawning periods per day (Kennedy 1977). Mate preference experiments showed *C. bovinus* females choose randomly between conspecific and sheepshead minnow (*C. variegatus*) males (Garrett 1980). **Threats:** *Cyprinodon bovinus* is at risk of introgressive hybridization with introduced *C. variegatus*. *Cyprinodon variegatus* was first found at Diamond-Y Draw in 1974, likely due to bait transport (Hubbs, 1980). Within one year, there was an extensive hybrid swarm throughout the lower segment of the creek (Kennedy 1977; Hubbs 1980). There is also evidence of an additional introduction of *C. variegatus* sometime after 1989 (Echelle and Echelle 1997). Additional threats include habitat alteration and pollution. Oil and gas fields surround the watercourse and a gas cracking plant is less than 1 km from Diamond-Y Springs (Echelle and Miller 1974). **Conservation Action:** In 1974, the Soil Conservation Service (Natural Resources Conservation Service) built a protective berm around Diamond-Y Spring (Hubbs 1980). After hybrids were discovered, eradication efforts (rotenone and selective seining) took place in 1976 and 1978 (Kennedy 1977; Hubbs 1980). The upper watercourse was not thought to be contaminated, so only the lower watercourse was treated. A refuge stock of *C. bovinus* from the upper watercourse was established at Dexter National Fish Hatchery in New Mexico. The selective elimination reduced genetic contamination (Hubbs, et al. 1978). An electrophoretic survey detected no evidence of introgression in 1982 (Echelle and Echelle 1997). A recovery plan for the Leon Springs pupfish was developed in 1985 (U.S. Fish and Wildlife Service 1985). In 1993 and 1994, genetic introgression was detected in both the upper (15%) and lower (6-7%) watercourses using mtDNA and allozymes. In 1998 the upper watercourse was renovated using antimycin and 550 pure *C. bovinus* from the captive stocks at Dexter National Fish Hatchery were subsequently released. In 2000, the lower watercourse was renovated by intensive seining and 2,300 *C. bovinus* from the captive stocks were released. In 2001, 5,000 more from the captive stocks were released throughout the system. Both renovation methods succeeded in reducing frequencies of non-native alleles, possibly to acceptable levels (as defined by Allendorf and Leary 1988). Most of the habitat is now owned by The Nature Conservancy of Texas, who bought the 608-ha Diamond-Y Spring Preserve in 1990 (Echelle and Echelle 1997). **Conservation Recommendation:** Continued monitoring of population and genetic structure is warranted. Further releases of Leon Springs pupfish from Dexter National Fish Hatchery would help to insure a natural genetic structure in the Diamond-Y system.

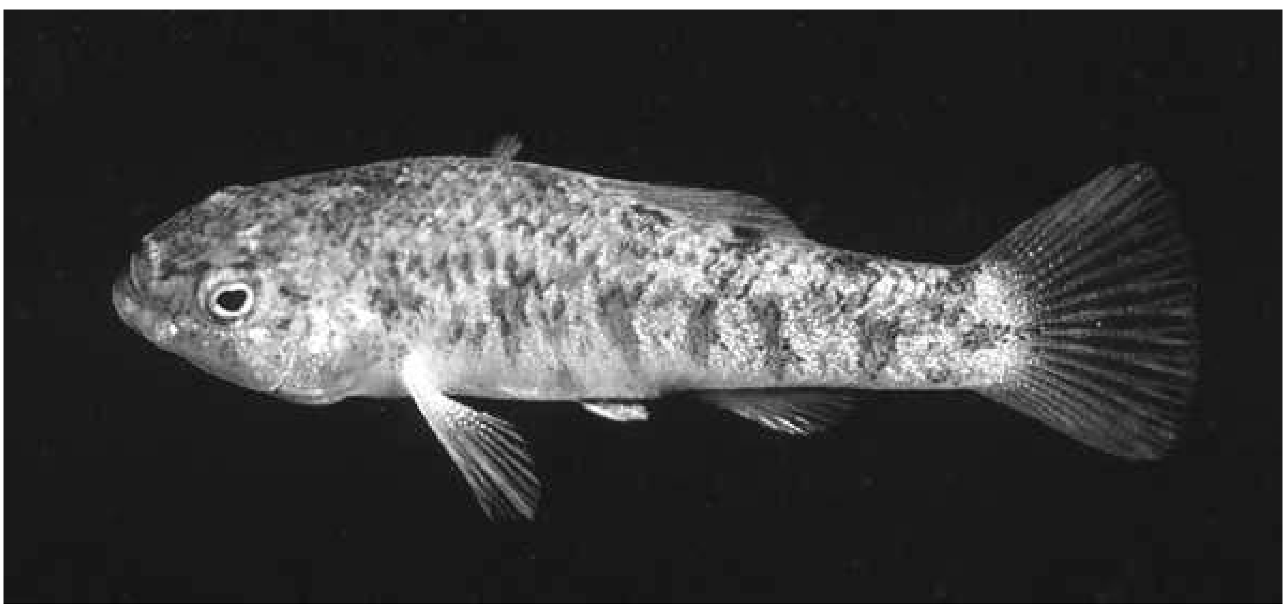
***Cyprinodon elegans* Baird and Girard 1853 (Cyprinodontidae)**

Common Name: Comanche Springs pupfish. **Conservation Status:** *Cyprinodon elegans* is listed as federally endangered by the United States (U.S. Fish and Wildlife Service 1967) and endangered by the state of Texas. **Identification:** The Comanche Springs pupfish, *Cyprinodon elegans,* is one of the most distinctive members of the genus *Cyprinodon*. Males possess a unique speckled color pattern and all individuals have a relatively streamlined body shape. They lack the vertical bars on the sides of their bodies that are found in most other *Cyprinodon*. Individuals attain a maximum size of approximately 50-mm SL (Itzkowitz 1969, Echelle and Hubbs 1978). Photo by G. Sneegas. **Distribution:** *Cyprinodon elegans* originally inhabited two isolated spring systems approximately 90 km apart in the Pecos River drainage of west Texas (Baird and Girard 1853). The type locality, Comanche Springs, inside the city limits of Fort Stockton (Pecos County), went dry in 1954 and has had only brief, intermittent flows since and that population is extinct (Hubbs and Springer 1957). The other population is restricted to the Balmorhea spring complex (Phantom, San Solomon, East Sandia and Giffin springs), and three artificial refugia (Phantom Lake Springs refugium canal, Balmorhea State Park refugium canal and San Solomon Ciénega) all near Balmorhea (Reeves County), Texas. Many canals were dug for irrigation in the Balmorhea region beginning in the mid-1870s (Brune 1981, U.S. Fish and Wildlife Service 1981) and continuing through the present. Marshes (ciénegas) presumed to have supported large numbers of *C. elegans* were drained and spring flows diverted into an irrigation network of concrete-lined canals with swiftly flowing water and dredged earth-lined laterals. This habitat is highly unnatural, ephemeral and wholly dependent upon local irrigation practices and other water-use patterns. San Solomon springs has been modified into a spring-fed swimming pool. **Abundance:** Estimated adult population densities are approximately 1,000 or more in the vicinity of San Solomon Springs and several thousand occur in the irrigation canals (Echelle 1975, U.S. Fish and Wildlife Service 1981). During a two-year sampling study (Garrett and Price 1993), population size in the park refugium canal was estimated to be as low as 968 (May 1990) and as high as 6,480 (September 1990). During 1999 to 2001, the population in San Solomon Ciénega averaged 270,000 in summer to approximately 18,000 in winter. **Habitat and Ecology:** Habitats currently occupied by *C. elegans* include modified springs, various irrigation canals and refugia designed to resemble the original natural habitat. Gut analysis of 20 specimens by Winemiller and Anderson (1997) revealed *C. elegans* eat mostly filamentous algae and some snails (*Cochliopa texana*). **Reproduction:** Breeding occurs over territories maintained by males. These territories are variable in size (averaging approximately 0.5 m^2) and most often located over algal mats. Eggs are guarded by the males who aggressively defend their territories against all intruders until the eggs hatch (Itzkowitz 1969). *Cyprinodon elegans* breeds in swifter water than any other *Cyprinodon*. Males orient and maintain position upstream from their territories until a female enters the territory and positions herself near the algal mat substrate (Itzkowitz 1969). Courtship behaviors are similar to other species of *Cyprinodon* based upon the direct observations of Itzkowitz (1969) as well the existence of natural hybrids between *C. elegans* and introduced *C. variegatus* as demonstrated by Stevenson and Buchanan (1973). Eggs are apparently laid singly onto the algal mat substrates of the male's territory (Itzkowitz 1969). Aquarium studies suggest females may lay 30 eggs per day and eggs hatch in 5 days at 20^{o} C (Cokendolpher 1978). **Threats:** The species is wholly dependent upon failing spring flows in the area and suffers as well from threats of hybridization and competition with introduced *C. variegatus* (U.S. Fish and Wildlife Service 1981). During 1998 and 1999, Phantom Lake dried twice and after the second drying, Phantom Lake Spring ceased to flow and ultimately the Phantom Lake Spring refuge canal dried. After the second drying, *C. elegans* increased in abundance in the uppermost spring pool until this pool also began to dry. During May 2000, a pump was installed by the U.S. Bureau of Reclamation to insure continuous flow in the upper spring pool. **Conservation Action:** A recovery plan for *C. elegans* has been developed (U.S. Fish and Wildlife Service 1981) and is in the process of being revised. Efforts have been made to improve habitat in the Balmorhea area. A small refugium canal was constructed in 1974 in Balmorhea State Park (Echelle and Hubbs 1978). Its presence on state park land provides a measure of security and for two decades has given park visitors the opportunity to view endangered species. In 1993, the Bureau of Reclamation constructed a modified 110-m canal at Phantom Lake Spring (Young et al. 1994) specially designed as pupfish habitat with sloped, sinuous sides to resemble a portion of a ciénega. In cooperation with local residents and farmers, in 1996 the construction of the 1-ha San Solomon ciénega was completed (McCorkle et al. 1998). This wetland is situated within the boundaries of the original, natural ciénega on state park land. Designed to resemble and function like the original ciénega, the native fish fauna, including *C. elegans*, has flourished. The park refugium canal, the Phantom Lake Springs refugium canal and the San Solomon Ciénega have increased numbers and security for the species, but each remains dependent on spring flows. The U.S. Fish and Wildlife Service is maintaining cultures of *C. elegans* at the Dexter National Fish Hatchery in Dexter, New Mexico and the Uvalde National Fish Hatchery, in Uvalde, Texas. The Dexter population came from an original stocking of 30 individuals taken from an irrigation canal leading from Giffin Springs (U.S. Fish and Wildlife Service 1981) and the Uvalde population came from an original stocking of 73 individuals from the distinctive subpopulation at Phantom Lake Springs (Garrett and Price 1993). **Conservation Recommendation:** The recommendations in the Comanche

Springs pupfish recovery plan should be implemented and additional efforts need to be directed to the recently failing Phantom Springs system.

***Cyprinodon eximius* Girard 1859 (Cyprinodontidae)**

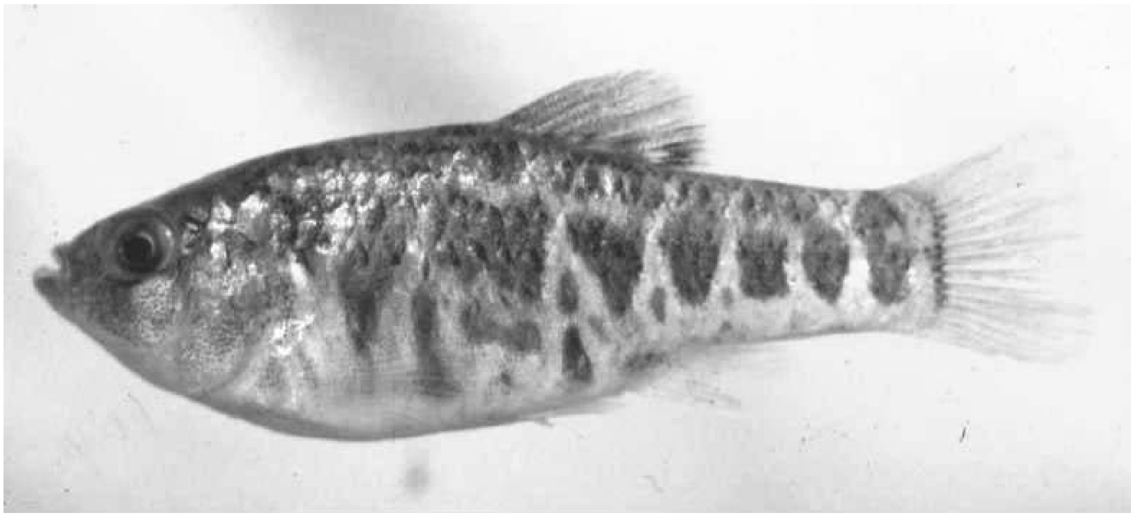
Common Name: Conchos pupfish. **Conservation Status:** *Cyprinodon eximius* is listed as threatened by the Texas Parks and Wildlife Department and as threatened by Mexico. **Identification:** *Cyprinodon eximius* can be distinguished by the caudal fin on mature males having black spots on the interradial membranes and the caudal fin bar being relatively wide preceded by a clear band (Miller 1976). The species is one of a complex of 12 pupfish species inhabiting what was once extensive Pleistocene bodies of water in the Chihuahuan Desert (Echelle and Echelle 1998). Photo by G. Sneegas. **Distribution:** The type locality of *C. eximius* is the Río Chuviscar, Ciudad Chihuahua, Mexico (Minckley 1980). This pupfish has a relatively wide-ranging distribution that includes streams of the Río Conchos and Río Sauz basins in Mexico and tributaries of the Rio Grande in Texas and Mexico (Echelle and Echelle 1998). The Rio Grande tributaries include: Alamito Creek, Presidio County, Texas; Río Alamo, Chihuahua; Tornillo Creek, Brewster County, Texas; and Devils River, Val Verde County, Texas (Miller 1981). Some of these populations may be subspecifically distinct (Miller 1976). *Cyprinodon eximius* was first taken in the Devils River during surveys by the Texas Game and Fish Commission in 1953 (Hubbs and Garrett 1990). Subsequent human activities (reservoir filling, stream rotenoning, etc.) reduced the Texas range to a small portion of the Devils River. In 1979 approximately 200 individuals from the remaining population were transported upstream, above a large waterfall, to reestablish them in one of their previous locations, Dolan Creek (Garrett 1980; Hubbs and Garrett 1990). **Abundance**: The species is still abundant in the Río Chuviscar (Edwards et al. in press) and elsewhere in the Río Conchos basin. Although the reestablished population in Dolan Creek is thriving (Garrett et al. 1992), most of the other Rio Grande tributary populations are sparse. **Habitat and Ecology:** Little is known of this species' biology or behavior. It is typically found in backwaters, stream margins and creek mouths (Minckley 1980). Adults rarely exceed 40 mm SL (Minckley 1980). **Threats:** Conchos pupfish inhabit environments with limited amounts of water that are facing increasing threats from a growing human population. As the region becomes more modernized, many aquatic environments are modified to accommodate this growth. **Conservation Action:** The Texas Parks and Wildlife Department and The Nature Conservancy of Texas now own most of Dolan Creek. The current recognition of threatened status by Mexico and the state of Texas is an important first step for conservation programs designed to protect this species. **Conservation Recommendation:** Further efforts need to be initiated to protect populations of this species throughout its range.



***Cyprinodon pecosensis* Echelle and Echelle 1978 (Cyprinodontidae)**

Common Name: Pecos pupfish. **Conservation Status:** *Cyprinodon pecosensis* is listed as a threatened species by Texas and New Mexico. **Identification:** *Cyprinodon pecosensis* has no scales on the abdomen, except for a patch anterior to the pelvic fins and one posterior to the gill membrane isthmus (Echelle and Echelle 1978). They are sexually dimorphic, particularly during the breeding season. Males have larger dorsal and anal fins, a dark bar on the distal portion of the caudal fin and an iridescent blue nape. In breeding males, the dorsal and anal fins are black (Echelle and Echelle 1978). Females are cryptically colored olive-brown with 7-9 dark lateral blotches and the dorsal fin is marked by a dark ocellus. Juveniles of both sexes have the female color pattern. Contrary to the typical pupfish pattern, young males may lose the dorsal ocellus before onset of sexual maturity (Garrett 1981a); however, in the presence of large, mature males, young adult males may retain the female color pattern (Garrett 1981a) as well as behavior (Kodric-Brown 1977). Courtship behavior and morphological characteristics place this species in the *C. variegatus* group of pupfishes (Liu 1965; Echelle and Echelle 1978). Echelle and Echelle (1978) postulated that this species arose through introgressive hybridization between ancestral *C. rubrofluviatilis* and *C. bovinus*, based on its morphological intermediacy and the geological history of the Trans-Pecos region. However, allozyme data in a subsequent phylogenetic analysis did not support this theory (Echelle and Echelle 1992). *Cyprinodon pecosensis* is presumed to have been isolated, at least from *C. rubrofluviatilis*, since the beginning of the Wisconsin glacial stage. Photo by G. Sneegas. **Distribution:** The type locality of the Pecos pupfish is an oxbow of the Pecos River at Bitter Lake National Wildlife Refuge, Chaves County, New Mexico (Echelle and Echelle 1978). *Cyprinodon pecosensis* is endemic to the Pecos River system from the vicinity of Roswell, New Mexico to the mouth of Independence

Creek, Terrell County, Texas. Its range is now restricted to just a few locations: Bitter Lake National Wildlife Refuge, Bottomless Lakes State Park, and sporadically in the Pecos River near Artesia, New Mexico and, in Salt Creek, a small tributary of the Pecos River in Texas. It also occurs sporadically in the Pecos River upstream of Artesia, New Mexico (Propst 1999). **Abundance:** During 1954, Pecos pupfish were the most abundant fish in the Pecos River between New Mexico and Sheffield, Texas (Echelle and Conner 1989; Wilde and Echelle 1992; Echelle et al. 1997). Abundance has declined dramatically since the early 1980s when non-native sheepshead minnows (*C. variegatus*) were inadvertently introduced into the Pecos River in Texas. The original introduction appears to have been in Red Bluff Reservoir (Childs et al. 1996). As a result, *C. pecosensis* has been eliminated from the lower Pecos River as far upstream as Loving, New Mexico and replaced by a hybrid swarm (Echelle and Conner 1989; Wilde and Echelle 1992; Echelle et al. 1997). The hybrid stocks suffered massive mortality during a golden alga (*Prymnesium parvum*) bloom in 1985 to 1988 in the entire 250-km reach of the Pecos River in Texas (Rhodes and Hubbs 1992). **Habitat and Ecology:** *Cyprinodon pecosensis* can occur in a variety of habitats and water quality conditions, ranging from highly saline sinkholes to typical desert streams. Their distribution is mostly limited by interspecific interactions and thus, they are typically found in habitats with low species diversity (Echelle and Echelle 1978). As with other members of the genus, they are opportunistic omnivores, feeding mainly on algae and detritus (Cox 1972; Naiman 1975, 1979; Davis 1981). **Reproduction:** Fish can reach reproductive maturity in less that one year at approximately 20 mm SL. Adult size seldom exceeds 50 mm SL. Few adults survive more than one year; winter populations consist primarily of fish born the previous summer (Kodric-Brown 1977; Garrett 1981b). Age at reproductive maturity, ovary size, egg size and egg number vary among populations, and are apparently associated with population density (Garrett 1982). With the exception of egg size, these reproductive traits can be altered in response to changing environments (Garrett 1982). Reproduction takes place from May through September (Garrett 1981b) and peaks during June and July when water temperatures are often >30° C (Kodric-Brown 1977). During the breeding season, males aggressively defend territories in shallow water and females enter only long enough to spawn. The male's territory seems to be chosen for topographic diversity and suitability of substrate for oviposition (Kodric-Brown 1978). Territory size is affected by competitive interactions (Kodric-Brown and Mazzolini 1992), with smaller territories evident during the peak of the breeding season (Kodric-Brown 1978). In dense populations, territories may take on a polygonal shape (Echelle et al. 1990). Smaller males are presumably unable to maintain territories with spawning sites that are attractive to females. Instead, these males will often enter a resident male's territory and surreptitiously attempt to fertilize eggs (Kodric-Brown 1977). Females enter the male's territory and after a brief courtship ritual, lay single, demersal eggs with a sticky coating. Females typically mate with several males over a period of days (Kodric-Brown 1977). **Threats:** The imperiled status of the Pecos pupfish is due to habitat losses and especially to hybridization with introduced *C. variegatus*. **Conservation Action:** A Conservation Agreement initiated in 1999 is designed to reduce further threats to the species and establish populations in newly created habitats adjacent to the Pecos River. **Conservation Recommendation:** Efforts should be directed to creating additional refugia for the remaining genetically pure populations of this species and to rehabilitating damaged and lost habitats.



Gambusia amistadensis Peden 1973 (Poeciliidae)

Common Name: Amistad gambusia. **Conservation Status:** *Gambusia amistadensis* was listed as an Endangered species in 1978 (U.S. Fish and Wildlife Service 1978) and was removed from the list in 1987 (U.S. Fish and Wildlife Service 1987). It is now considered extinct by the U.S. Fish and Wildlife Service and by the state of Texas. **Identification:** The Amistad gambusia is a member of the *Gambusia senilis* species group and is closely related to *G. hurtadoi*, *G. alvarezi*, *G. gaigei*, and *G. senilis* (Rauchenberger 1989). The species is characterized by its relatively slender body, terminal mouth with numerous teeth on each jaw, and males having long serrae on ray 4p of the gonopodium. Preserved specimens have strong crosshatching and numerous darkly pigmented crescent-shaped spots on their scale margins. The mid-dorsal stripe is narrow and the lateral stripe is broad. A short, dusky subocular bar is present. Adult females have a permanent median dark anal spot (Peden 1973). Photo by G. Sneegas. **Distribution:** The Amistad gambusia was originally described from Goodenough Springs (29°32'10"N, 10°15'10"W) in Val Verde County, Texas. The original range of the species included the headsprings and the 1.3 km spring run downstream to its confluence with the Rio Grande (Peden 1973). **Abundance:** The species became extinct in the wild when Goodenough Springs, once the third largest spring system in Texas, was inundated following the closing of the dam gates of Amistad Reservoir in 1968 (Peden 1973, Brune 1981). **Habitat and Ecology:** Goodenough Springs and its warm spring run rapidly flowed over limestone gravel and sand substrates along its course to the Rio Grande. Waters originated in the relatively large Edwards-Trinity aquifer (Peckham 1963) and maintained flow rates of approximately 2,000-4,000 l^3/s (Brune 1981). The type locality and habitat for the Amistad gambusia is now under approximately 30 m of water and former spring openings are now recharge zones (Peden 1973, Brune 1981). Little is known concerning the food habits of the Amistad gambusia; however, the gut contents of 10 paratypes examined by Peden (1973) contained mostly unidentified items, some insect fragments and traces of filamentous algae. Other fishes of conservation concern co-occurring with the Amistad gambusia prior to the inundation of its habitat included: *Cyprinella proserpinus* (proserpine shiner), *Macrhybopsis aestivalis* (speckled chub), *Notropis braytoni* (Tamaulipan shiner), *N. jemezanus* (Rio Grande shiner) and *Cycleptus elongatus* (blue sucker) (Peden 1973). **Reproduction:** Observations in aquaria by Peden (1970, 1973) indicated that male courtship appeared similar to that found in other poeciliids and that pregnant female *G. amistadensis* gave birth to their young in vegetated areas. Of 10 female paratypes examined by Peden (1973), the mean size was 29.8 mm SL (range = 25.9 to34.6 mm SL) and 7 contained 5 to 11 (mean 8.9) embryos in each ovary while the other 3 females contained 1 to 7 eggs. **Threats:** Goodenough Springs, the only habitat for this species is now under Amistad Reservoir and not available for *G. amistadensis*. **Conservation Action:** Culture populations of *G. amistadensis* were maintained until the late 1970s at the University of Texas at Austin and at the U.S. Fish and Wildlife Service's endangered species culture facility in Dexter, New Mexico (Hubbs and Jensen 1984).

These populations were contaminated by western mosquitofish (*G. affinis*), which eliminated the *G. amistadensis* in these cultures prior to 1983 (Hubbs and Jensen 1984). This species is now extinct.

***Gambusia gaigei* Hubbs 1929 (Poeciliidae)**

Common Name: Big Bend gambusia. **Conservation Status:** *Gambusia gaigei* is listed as federally endangered by the United States (U.S. Fish and Wildlife Service 1967) and endangered by the state of Texas. **Identification:** The species is a relatively plain, yellowish member of the Poeciliidae up to 30-mm long, whose faint lateral stripe is the most pronounced dark mark on the body. There is also a suborbital bar and a faint, dark chin bar. The gonopodium has a pronounced elbow, with only one or two segments. Photo courtesy Texas Parks and Wildlife Department. **Distribution:** *Gambusia gaigei* was described by Hubbs (Hubbs 1929) based on specimens collected by F. M. Gaige from "a marshy cattail slough fed by springs, located close to the Rio Grande at Boquillas, Brewster County, opposite the Mexican village of the same name." Apparently this was the largest river-side spring in the Big Bend region (Hubbs 1940). Subsequently in June 1954, numerous specimens were obtained from Graham Ranch Warm Springs (Hubbs and Springer 1957). Graham Ranch Warm Springs (now known as Spring 4) is the largest spring near Boquillas but is one km to the west. Other springs also existed at Boquillas that may have been the source of Gaige's captures. Those springs dried in 1954 and no longer contain fish. It is more likely, however, that the original collections came from Graham Ranch Warm Springs. Although Big Bend gambusia were abundant in Graham Ranch Warm Springs and the newly constructed "kiddie fishing pool" in 1954, they were scarce by 1956 and the previously scarce western mosquitofish (*G. affinis*) was very abundant. Consequently, renovation efforts were initiated on 9 October 1956. Intensive seining obtained 25 individuals and the area was treated with rotenone and fewer than 12 other *G. gaigei* (and thousands of *G. affinis*) killed. The 25 remaining individuals were placed in five locations: Boquillas Spring, Glenn Springs and, a stock tank along the Glenn Springs Road (15 individuals); a metal tank near the park headquarters (6 individuals); and, 4 individuals that were taken to the University of Texas at Austin. The fish placed at the Boquillas and Glenn Springs areas were never seen again. The fish at the park headquarters flourished until cold winter temperatures killed them all. One of the four remaining fish died in Austin, but the other three (one female and two males) were returned to the park and put into a newly constructed pond where they flourished (Hubbs and Broderick 1963). At the same time the Rio Grande Village Camp Ground was established near the Graham Ranch Warm Spring (and the existing four springs in the area renamed to Springs 1 to 4). Trees were planted to shade the camp ground and watered via an irrigation ditch from the Rio Grande. That water drained into the Big Bend gambusia refugium pond. *Gambusia affinis* also got into those irrigation ditches and subsequently into the refugium pond. When the refugium pond was examined on 16 April 1960, only 27 *G. gaigei* individuals were obtained. All were taken to the University of Texas at Austin. Half of these were sent to the University of Michigan for insurance against extinction. Both cultures flourished and after a second refugium pond (using water from Spring 1) was constructed, the species was returned on 8 August 1960 to the park. With two intervals of extreme scarcity, it is not surprising that the surviving population is homozygous (Echelle 1991). Minor problems (such as the introduction of green sunfish, *Lepomis cyanellus*, and mortalities due to an extremely cold winter) did not further threaten the survival of *G. gaigei* (Hubbs and Williams 1979). Subsequently, all Spring 4 water was diverted to the campground and the "kiddie fishing pool" dried. Later a flash flood ran through the Spring 1 refugium pond, reintroducing *G. gaigei* into their original habitat. Increased pumping caused the Spring 1 refugium pond to overflow through its drainage pipe. Fish moved from the refugium pond into the overflow ditch and today, the species flourishes in both locations. Eventually, water leaked from the Spring 4 pool and some Big Bend gambusia moved into a large beaver pond located between the Spring 4 refugium and the Rio Grande **Abundance:** All *G. gaigei* are descendents of the three individuals taken in 1956 (Hubbs and Broderick 1963, Hubbs and Echelle 1972). At present, several thousand Big Bend gambusia inhabit the two spring pool refugia and the Spring 1 drainage ditch. Smaller populations also occur in the Beaver Pond and in the Spring 4 pool. **Habitat and Ecology:** Little is known about most aspects of the life history of this species in its natural environments; however, it is apparent that *G. gaigei* can compete with *G. affinis* only in stenothermal warm spring environments and is unsuccessful in habitats with more eurythermal conditions (U.S. Fish and Wildlife Service 1984). The species is often found in dense stands of *Chara* that is found in the refugia ponds (U.S. Fish and Wildlife Service 1984). Big Bend gambusia have been found in association with at least six other fish species. These include *Notropis braytoni* (Tamaulipan shiner), *Cyprinella lutrensis* (red shiner), *G. affinis* (western mosquitofish), *Ictalurus punctatus* (channel catfish), *Lepomis cyanellus* (green sunfish) and the exotic *Oreochromis aurea* (blue tilapia). Citizens wishing to help the conservation efforts planted the channel catfish and green sunfish in the Spring 4 refugium; these were removed by park officials prior to their having an adverse impact on *G. gaigei*. The blue tilapia gained access to the overflow pond below Spring 4 after severe flooding of the Rio Grande in the early 1990s. Their impact on *G. gaigei* is unknown. **Reproduction:** Big Bend gambusia presumably reproduce year-round and fecundities have been found to be high in June (up to 50 young in small mature females) and lower in August and January (up to 30 young in large females) Hubbs and Mosier 1985). **Threats:** Big Bend gambusia have undergone an extreme genetic bottleneck approximately fifty years ago. The limited quantities of warm spring waters available, park campground development in the area and the loss of the species natural habitats in Boquillas

Spring and Graham Ranch Warm Springs further limit this species recovery. **Conservation Action:** A recovery plan has been prepared for this species (U.S. Fish and Wildlife Service 1984) and the National Park Service has increased their vigilance toward the protection of *G. gaigei*. **Conservation Recommendation:** Full implementation of the recovery plan for this species would allow greater understanding of the ecological requirements of *G. gaigei* and would direct the development of the National Park's campground facilities at this location in a manner that would enhance the conservation of this species.

***Gambusia georgei* Hubbs and Peden 1969 (Poeciliidae)**

Common Name: San Marcos gambusia. **Conservation Status:** *Gambusia georgei* is listed as federally endangered by the United States (U.S. Fish and Wildlife Service 1980) and endangered by the state of Texas. **Identification:** The San Marcos gambusia is a plainly marked poeciliid and is subtly different from the sympatric western mosquitofish, *G. affinis* and distinctly different from the sympatric *G. geiseri* (largespring gambusia). The scales of *G. georgei* tend to be strongly crosshatched in contrast to the less distinct markings on the scales of *G. affinis*. In addition, *G. georgei* tend to have a prominent dark pigment stripe across the distal edges of their dorsal fins and, in dominant individuals, a diffuse mid-lateral stripe extending posteriorly from the base of the pectoral fin to the caudal peduncle. A dark subocular bar is present and the caudal fin has few spots or dusky pigmented regions. The median fins of wild-caught specimens of San Marcos gambusia tend to be lemon yellow. In a dominant or "high" male, this color can approach a bright yellowish-orange, especially around the gonopodium. A bluish sheen is evident in more darkly pigmented individuals, especially near the anterior dorsolateral surfaces of adult females (Hubbs and Peden 1969, Edwards et al. 1980). *Gambusia geiseri*, by contrast, has a black post-anal streak, numerous spots on the sides of their bodies and numerous melanophores around their snouts. The San Marcos gambusia is a member of the *Gambusia nobilis* species group, and is closely related to *G. heterochir, G. krumholzi* and *G. nobilis* (Rauchenberger 1989). *Gambusia georgei* is unique morphologically from other *Gambusia* species in several characters, including the presence of more than five elbow segments in ray 4a of the gonopodium and by the presence of a compound claw on the end of gonopodial ray 4p (Hubbs and Peden 1969). Photo by R. Edwards. **Distribution:** The San Marcos gambusia was restricted to the headwaters of the San Marcos River, within the City of San Marcos, Hays

County, Texas. The species was found in collections taken in 1884 by Jordan and Gilbert during their surveys of Texas stream fishes and in later collections (as a hybrid with *G. affinis*) taken in 1925 (Hubbs and Peden 1969). Unfortunately, records of exact sampling localities are not available for these earliest collections. Localities were merely listed as "San Marcos Springs." These collections likely were taken at or near the headsprings area since samples taken downstream from the headsprings, prior to the 1950s, are extremely scarce. However, at least one of Jordan and Gilbert's collections (the type series of the federally Endangered fountain darter, *Etheostoma fonticola*) was at the confluence of the San Marcos and Blanco Rivers, 6 km downstream from the headsprings. Since that time, nearly every specimen of *G. georgei* has been taken approximately 3 km downstream from the headsprings in a 1-km stretch of the San Marcos River (Longley 1975, Edwards et al. 1980). **Abundance:** During an extensive study of the species during the late 1970s, *G. georgei* was extremely rare accounting for only 0.09% of all *Gambusia* captured (Edwards et al. 1980). **Habitat and Ecology:** *Gambusia georgei* have been found mostly over muddy but not silted substrates, and generally in shaded or partially shaded habitats (Hubbs and Peden 1969, Edwards et al. 1980). **Reproduction:** There is little information on the reproductive capabilities of *G. georgei*. Two individuals kept in laboratory aquaria produced 12, 30 and 60 young, although the largest clutch appeared to have been aborted and did not survive (Edwards et al. 1980). Hybridization between *G. georgei* and *G. affinis* was first noted by Hubbs and Peden (1969) and the production of hybrid individuals between them continued for many years without obvious introgression of genetic material into either of the parental species. However, during the series of collections taken during the early 1980s, hybrid individuals were many times more abundant than "pure" *G. georgei* (U.S. Fish and Wildlife Service 1984, 1996). **Conservation Action:** An endangered species recovery plan is in effect for the conservation of this species (U.S. Fish and Wildlife Service 1996); however, the prognosis for recovering this species is, at best, remote. Although the San Marcos River has been extensively sampled throughout the past five decades, the last individual of this species was taken in 1982. The San Marcos gambusia is, in all likelihood, extinct.

***Gambusia heterochir* Hubbs 1957 (Poeciliidae)**

Common Name: Clear Creek gambusia. **Conservation Status:** *Gambusia heterochir* is listed as federally endangered by the United States (U.S. Fish and Wildlife Service 1967) and endangered by the state of Texas. **Identification:** *Gambusia heterochir* is a member of the *Gambusia nobilis* species group (Rauchenberger 1989). It is a relatively stocky gambusia with a metallic sheen. Scattered terminal dark marks on many lateral or dorsal scales form distinctive crescentric marks. Females have a more pronounced anal spot than that found in western mosquitofish, *G. affinis*. Males are distinct by having a unique notch in their pectoral fins. Photo by R. Edwards. **Distribution:** The species was first collected in the headwaters of Clear Creek, Menard County, Texas, in 1953 and is restricted to this spring environment (Hubbs 1957). Clear Creek arises from a series of springs (= Wilkinson Springs) on a limestone bluff 16 km west of Menard. **Abundance:** Thousands of Clear Creek gambusia occupy the 1-ha head pool formed by a small earthen dam built in 1880. **Habitat and Ecology:** Another dam was constructed downstream from the head pool in 1933 that formed a much larger pool that abuts the 1880 dam. The downstream pool is occupied by large numbers of *G. affinis*, which compete and hybridize with *G. heterochir* (Hubbs 1957). The two sympatric *Gambusia* live in different environmental conditions: stenothermal water with neutral pH favors *G. heterochir* and eurythermal water with a pH near 8 favors *G. affinis*. Both species flourish in either environment but competition favors the fish in their respective environments. The spring pool is stenothermal and the downstream pool eurythermal and are separated by the 2-m wide 1880 dam (Hubbs 1971). **Reproduction:** Females have an interbrood interval of 47 days at 20^{o} C (Hubbs 1995) and begin reproducing at 16 mm SL. Females may be mature in three months and seldom live longer than one year (Hubbs 1971). Large females (up to 45 mm SL) have many more young than smaller females. Males place their gonopodia on their unique pectoral fins during copulation (Peden 1970). Although the two species differ in reproductive anatomy and behavior, those differences are not sufficient to preclude hybridization (Peden 1970). **Threats:** At present, *G. heterochir* is very abundant in the head pool but is potentially threatened by diminished spring flows from water withdrawals from the Edwards-Trinity aquifer. **Conservation Action:** A recovery plan for this species has been developed (U.S. Fish and Wildlife Service 1982). When the 1880 dam began to collapse, it was repaired and the source of *G. affinis* ingress was blocked in 1980 (Edwards and Hubbs 1985). Subsequently, hybridization frequency and competition was drastically reduced. **Conservation Recommendation:** The recovery objectives listed in the Clear Creek Gambusia Recovery Plan needs to be fully implemented.

Gambusia nobilis Baird and Girard 1853 (Poeciliidae)

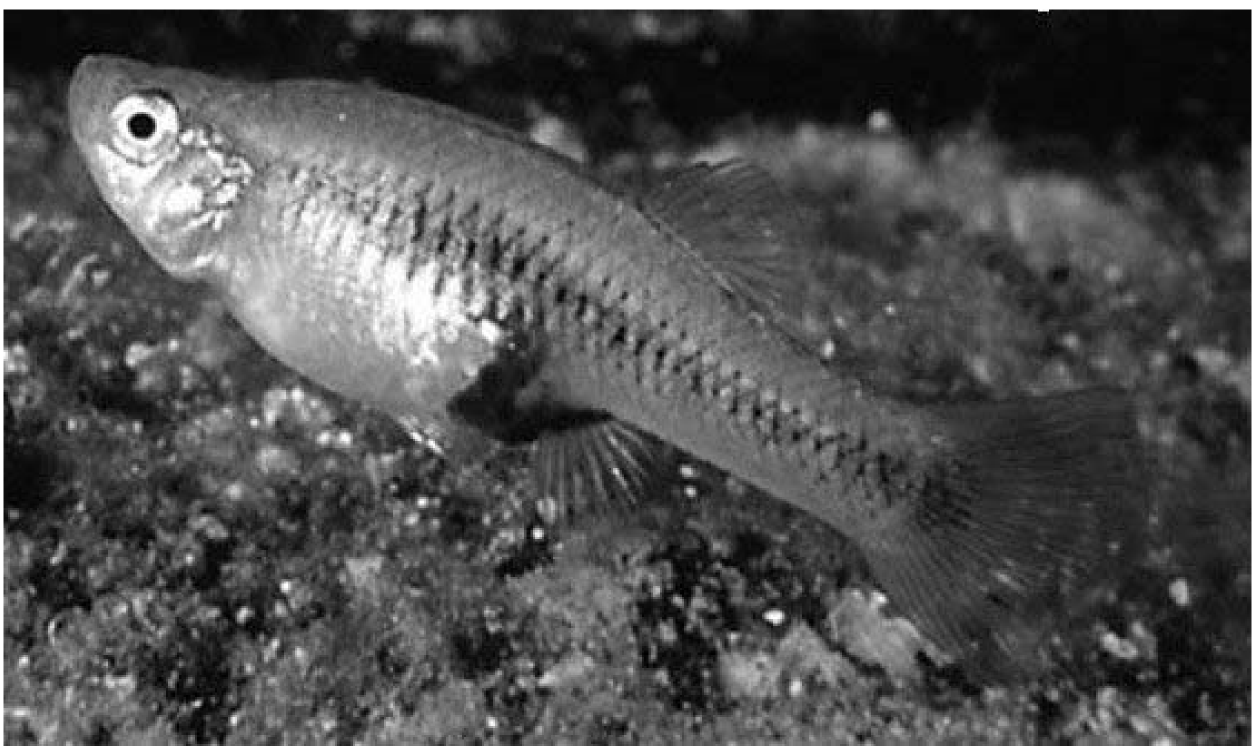
Common Name: Pecos gambusia. **Conservation Status:** *Gambusia nobilis* is listed as federally endangered by the United States (U.S. Fish and Wildlife Service 1970) and endangered by the states of New Mexico and Texas. **Identification:** The Pecos gambusia is a relatively robust *Gambusia*, with an arched back and a caudal peduncle depth that is approximately two-thirds of the head length. The margins of the scale pockets are outlined in black and spots are normally absent on the caudal fin, however, sometimes a faint medial row of spots may be present. The dorsal fin has a subbasal row of spots. Females have a prominent black area on the abdomen that surrounds the anus and anal fin. The male gonopodium has a number of unique features including elongated spines on ray 3, small rounded hooks on the tips of rays 4p and 5a, and an elbow on ray 4a consisting of 3 or 4 fused segments located opposite the serrae of ray 4p. *Gambusia nobilis* generally have 8 dorsal, 12 pectoral, 9 to 10 anal, and 6 pelvic rays (Hubbs and Springer 1957, Koster 1957, Bednarz 1975, Echelle and Echelle 1986). Populations in Toyah Creek (Texas) and Blue Spring (New Mexico) were found to be the most diverse morphologically and genetically and the Toyah Creek population had the greatest genetic heterogeneity (Echelle and Echelle 1986, Echelle et al. 1989). Photo by G. Sneegas.

Distribution: *Gambusia nobilis* was described by Baird and Girard (1853) based on material from Leon and Comanche springs, Pecos County, Texas. Leon Springs was later designated the type locality (Hubbs and Springer 1957). The species is endemic to the Pecos River basin in southeastern New Mexico and western Texas and originally ranged from near Fort Sumner, New Mexico to the area around Fort Stockton, Texas. At present, the species is restricted to four main areas, two in New Mexico and two in Texas. Populations live in various springs and sinkholes in Bitter Lake National Wildlife Refuge, near Roswell, New Mexico; Blue Spring, east of Carlsbad

Caverns National Park, New Mexico; the Diamond-Y springs and draw (=Leon Creek); near Fort Stockton, Texas; and the Balmorhea spring complex and Toyah Creek near Balmorhea, Texas. Extirpated populations include the Pecos River near Fort Sumner and North Spring River in New Mexico, and Leon and Comanche springs, which are now dry, in Texas. **Abundance:** Where suitable habitats exist, Pecos gambusia populations can be dense. An estimated 27,000 individuals inhabit the Bitter Lake National Wildlife Refuge area, and 900,000 inhabit Blue Spring (Bednarz 1975, 1979). Approximately 100,000 Pecos gambusia are estimated to inhabit the Balmorhea spring complex and more than 100,000 in the Diamond-Y springs and draw (U.S. Fish and Wildlife Service 1983). **Habitat and Ecology:** Pecos gambusia inhabit stenothermal springs, runs, spring-influenced marshes (ciénegas), and irrigation canals carrying spring waters (U.S. Fish and Wildlife Service 1983). Some populations are also known from areas with little spring influence; these habitats generally have abundant overhead cover, and include, sedge covered marshes and gypsum sinkholes (Echelle and Echelle 1980). One or two other *Gambusia* may also be found in association with *G. nobilis*. Where the western mosquitofish (*G. affinis*) is found, *G. nobilis* inhabits stenothermal waters and *G. affinis* is most often found in eurythermal habitats. Where the largespring gambusia (*G. geiseri*) has been introduced, the Pecos gambusia is much more likely to be found associated with vegetation or in deeper waters, while *G. geiseri* tends to be at the surface or in open water over non-vegetated substrates (Hubbs et al. 1995). Pecos gambusia feed relatively non-selectively, consuming a diversity of food types, including; amphipods, dipterans, cladocerans, filamentous algae, arachnids and mollusks (Hubbs et al. 1978, Winemiller and Anderson 1997). **Reproduction:** *Gambusia nobilis* produce live young. Bednarz (1979) reported that the number of embryos was related to female size and that the mean number of embryos was 38 in the Blue Spring population. Hubbs (1996) found that the birth weight of Pecos gambusia from Texas populations ranged between 35 and 50 mg and females had an interbrood interval of 52 days. Hybrids between *G. nobilis* and *G. affinis* or *G. geiseri* are occasionally found, especially in habitats where one of the species is rare (Hubbs and Springer 1957, U.S. Fish and Wildlife Service 1983). **Threats:** Pecos gambusia face severe threats from spring flow declines and habitat modification throughout their range. In parts of their range, ciénegas, presumed to have supported large numbers of *G. nobilis*, were drained and spring flows diverted for irrigation. San Solomon springs has been modified into a spring-fed swimming pool. During 1998 and 1999, Phantom Lake (part of the Balmorhea spring complex) dried twice and after the second drying, Phantom Lake Spring ceased to flow and ultimately the Phantom Lake Spring refuge canal dried. During May 2000, a pump was installed by the U.S. Bureau of Reclamation to insure continuous flow in the upper spring pool. Additional stresses on the population may occur through competition with the introduced *G. geiseri*. **Conservation Action:** A recovery plan for *G. nobilis* has been developed (U.S. Fish and Wildlife Service 1983). Efforts have been made to improve habitat in the Balmorhea area. A small refugium canal was constructed in 1974 in Balmorhea State Park (Echelle and Hubbs 1978). In 1993, the Bureau of Reclamation constructed a modified 110-m canal at Phantom Lake Spring (Young et al. 1994) with sloped, sinuous sides to resemble a portion of a ciénega. In cooperation with local residents and farmers, in 1996 the construction of the 1-ha San Solomon Ciénega was completed (McCorkle et al. 1998). This wetland is situated within the boundaries of the original, natural ciénega on state park land. Designed to resemble and function like the original ciénega, the native fish fauna, including *G. nobilis*, has flourished. The park refugium canal, the Phantom Lake Springs refugium canal and the San Solomon Ciénega have increased numbers and security for the species, but each remains dependent on spring flows. The renovation of the Diamond-Y

Draw in 1998 (to reduce genetic contamination of the Endangered Cyprinodon bovinus) removed G. geiseri from that system (Echelle and Echelle 1997). Additional protection for *G. nobilis* stems from its presence in Balmorhea State Park, Bitter Lake National Wildlife Refuge, Diamond-Y Draw which is owned by the Nature Conservancy of Texas and an introduced stock of Pecos gambusia in artificial pools at the Living Desert State Park near Carlsbad, New Mexico.

Conservation Recommendation: The recommendations in the Pecos gambusia recovery plan should be implemented and additional efforts need to be directed to the recently failing Phantom Springs system.



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