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Population Status and Life History Attributes of the Texas Shiner Notropis amabilis

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ABSTRACT.—Purposes of this study were to assess population status and life history attributes of the Texas Shiner *Notropis amabilis*, a minnow endemic to the Edwards Plateau region in Texas and the Rio Grande drainage of U.S.A. and Mexico. Despite possible extirpation from three stream reaches, populations of Texas Shiners persist with abundances categorized as occasional and frequent among multiple and independent stream reaches, streams, and drainages. Therefore, Texas Shiner population is considered stable. Quantification of life history traits suggest Texas Shiner has a protracted reproductive season (*i.e.*, 9 mo), a life span of 2 y, and feeds on primarily aquatic invertebrates. Protracted spawning seasons are consistent with Texas Shiner's reported associations with spring systems of the Edwards Plateau. Current and future conservation of *N. amabilis* and other spring-associated fishes are explicitly linked to spring complexes, although exact mechanisms of association are unknown.

INTRODUCTION

Notropis amabilis (Girard) (Texas Shiner) is a small bodied cyprinid with a distribution restricted to the Edwards Plateau region of Texas and Rio Grande drainage of U.S.A. and Mexico (Hubbs *et al.,* 2008). Texas Shiner is in the subgenus *Notropis* and its closest extant relatives are Rio Grande Shiner *Notropis jemezanus*, Sharpnose Shiner *Notropis oxyrhynchus*, and Emerald Shiner *Notropis atherinoides* (Bielawski and Gold, 2001). Although the paleobiogeography of Texas Shiner is currently unclear, a proposed pathway of speciation is that the subgenus *Notropis* ancestor gained access to the Pecos River from the north through historical connections with eastern flowing drainages of the Southern Great Plains during the Neogene (Conner and Suttkus, 1986) or Quaternary (Echelle and Echelle, 1978) periods. A later derived ancestor of Texas Shiner and its closest phylogenetic relative Rio Grande Shiner (Bielawski and Gold, 2001) were exchanged through Pleistocene connectivity between the Pecos River and Edwards Plateau drainages (*e.g.*, Colorado River) and eventually the Rio Grande drainage (Echelle and Echelle, 1978). During Pleistocene interglacial climates, the ancestral form of Texas Shiner became isolated in refugia of persistent spring complexes within the Edwards Plateau drainages (Coburn, 1982).

Current distribution of Texas Shiner is within and downstream from spring complexes from the San Gabriel River in the Brazos River basin on the northeast extent of its range, to

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the Pecos River basin in the west, and to the Rio Grande basin in the south (Garrett *et al.*, 2002; Hubbs *et al.,* 2008). Due to its limited distribution and association with spring complexes of the Edwards Plateau region, Texas Shiner is considered a Species of Greatest Conservation Need (SGCN) by Texas Parks and Wildlife since 2001; however, population status of Texas Shiner is largely unknown. Texas Shiner associates with clear water, pool habitats, and moderate current velocities (0.1 m/s) and sand, gravel, cobble, and bedrock substrates (Bean *et al.*, 2007; Kollaus and Bonner, 2012). Other life history attributes (*i.e.,* reproductive ecology and food habits) have not been investigated. Understanding of current conservation status and life history attributes will benefit conservation efforts of Texas Shiner and provide additional insights into life history traits selected among a phylogenetically diverse community of spring-associated fishes.

Purposes of this study were to assess population status within the known range of Texas Shiner distribution and to describe basic life history attributes. Based on latitudinal trends of reproductive seasons (Gotelli and Pyron, 1991), Texas Shiner would be expected to have a 5.5 mo reproductive season. However, other spring-associated fishes of the Edwards Plateau have a protracted reproductive season likely influenced by the stenothermal water of spring complexes within the Edwards Plateau (Hubbs, 1985; Hubbs, 1998; Perkin *et al.,* 2012). We predict Texas Shiner, as a spring-associated species, will have more protracted reproductive season than expected, based on latitude. We also expect food habits and other life history traits will be similar to those reported for its phylogenetic relatives *N. jemezanus*, *N. oxyrhynchus,* and *N. athernoides*. Specifically, that Texas Shiner will consume invertebrates (Sublette *et al.,* 1990, Marks *et al.,* 2001) or plankton (Goldstein and Simon, 1999), have a short life span, and produce multiple clutches within the reproductive season (Durham, 2007). Life history attributes assessed in this study were age at maturation, length and age relationships, length of reproductive season, number and size of oocytes, gut content, frequency of occurrence, and gut percent composition.

MATERIALS AND METHODS

Occurrences and relative abundances of Texas Shiner were obtained from museum records, published literature, and unpublished data spanning a collection period between 1850 and 2015. Major gulf slope drainages within the reported range of Texas Shiner were represented by at least one stream; however, not all streams within a drainage were included, because either a museum voucher was not available or relative abundances could not be calculated from the available data. Named streams (*e.g.,* San Gabriel River) or reaches of a named stream (*e.g.*, upper San Marcos River) were included in our population assessment if a museum record of Texas Shiner existed and if relative abundances were available in published or unpublished form. Museum records (Fishes of Texas Project Database, Version 2; Hendrickson and Cohen, 2015) were used to document occurrences in stream or stream reaches. Unverified records within the Fishes of Texas Project Database were excluded. For museum records the earliest date of record was used when more than one record existed for a stream or stream reach. Relative abundances from more recent published and unpublished reports were calculated by stream or stream reach and were categorized using the Abundance, Common, Frequent, Occasional, Rare (ACFOR) scale per stream or stream reach: abundant (>75% in relative abundance), common (50–75%), frequent (25–49%), occasional (5–24%), and rare (1–4%) (Kent and Coker, 1992; Stiers *et al.,* 2011). Failure to detect Texas Shiner (*i.e.*, 0% in relative abundance) suggests, but does not confirm, possible extirpation. In addition some published and unpublished reports provided

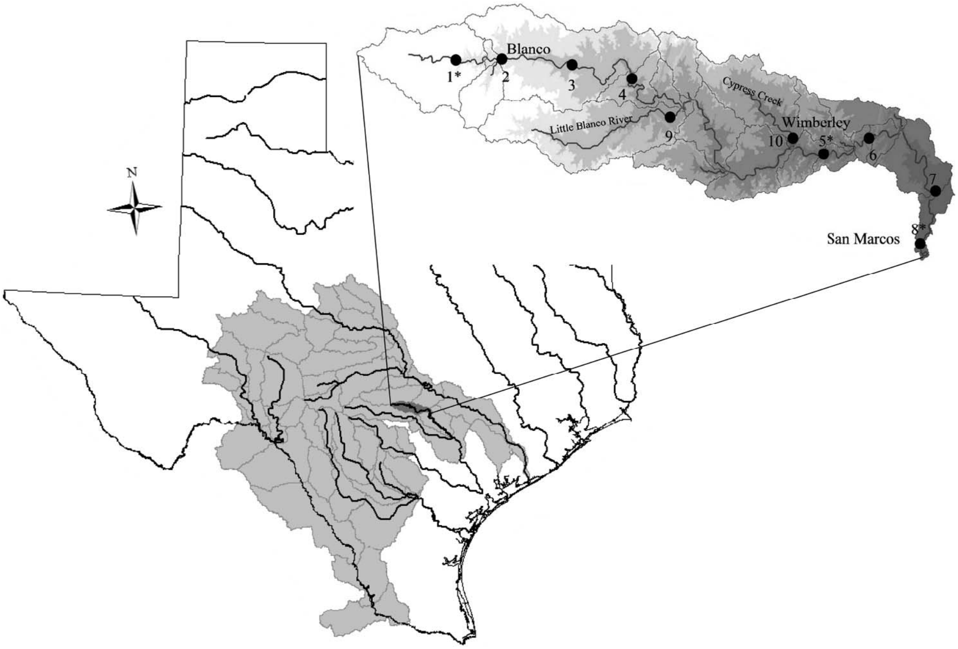

FIG. 1.—Map of *N. amabilis* range (light gray) and study sites within the Blanco River drainage. Range comprised of confirmed museum vouchers within a USGS Hydrological Unit (HUC) level-8 (asterisks denote sites of monthly diet and reproduction collections)

statistical assessments on temporal trends in Texas Shiner relative abundances. When applicable, population status (*i.e.*, increasing, stable, decreasing trends) per stream or stream reach was noted.

Age and length information was obtained from 10 sites sampled monthly from October 2003 to July 2005 in the Blanco River basin. The Blanco River drains 600 km^2 of the Guadalupe River drainage and is typical of many Edwards Plateau streams by having clear hard water and predominately bedrock substrates. The Blanco River is modified by numerous low-head dams, groundwater withdrawals, municipal and agriculture runoff, and wastewater effluents (Bean *et al.,* 2007). Despite these anthropogenic stressors, fish assemblage structure (*e.g.*, taxa occurrence and abundance) is similar to other Edwards Plateau streams and consists of a diverse group of native fishes. Sites were spaced along the Blanco River main stem from near the headwaters to the confluence with the San Marcos River. Sites and locations (Fig. 1) were as follows:1 (30°6′14.84″N, 98°35′2.63″W), 2 (30°5′35.96″N, 98°25′18.30″W), 3 (30°5′1.87″N, 98°19′19.16″W), 4 (30°3′18.12″N, 98°17′12.08″W), 5 (29°59′3.05″N, 98°2′33.61″W), 6 (30°0′16.72″N, 97°57′14.50″W), 7 (29°56′13.55″N, 97°53′42.58″W), and 8 (29°52′16.54″N, 97°54′56.28″W). Site 9 (Little Blanco River, 30°2′27.00″N, 98°15′8.89″W) and Site 10 (Cypress Creek, 29°59′48.93″N, 98°5′50.64″W) were located in the two largest tributaries of the Blanco River. At each site available geomorphic units (*i.e.*, riffles, runs, and pools) were sampled quarterly with a backpack electrofisher (Smith-Root Model 12-B POW) and seines (1.2 by 4.3 m, mesh size: 3.2 mm; 1.8 by 3.7 m, mesh size: 3.2 mm). Texas Shiners were enumerated, measured to the nearest mm, and released. Temporal, number collected by site, and spatial habitat associations are reported in Bean *et al.* (2007). Modal progression analysis (MPA) in Fish Stock Assessment Tools, version 2 (FiSAT II; Gayanilo *et al.,* 2005) was used to estimate age group and mean total lengths (±1 SD) of each age group. Bhattacharya's Method in MPA uses an iterative process, Gaussian function, and time-series length-frequency histograms to estimate number of age groups and mean length (±1 SD) for each age group. Mean total length per age group was the January mean total length, which represents the maximum growth within the preceding year.

In addition to quarterly sampling, nine to 10 adult Texas Shiners were collected monthly at each site from October 2003 to September 2004, exposed to a lethal dose of MS-222 (80 mg/liter) in accordance with IACUC permit 06-0620_802, and preserved in 10% formalin for reproductive analyses and diet. In the laboratory total length (nearest mm) and weight (nearest 1 mg) of preserved specimens were measured. Using a dissecting microscope, gonads were removed, sexed, and weighed for determination of gonadosomatic indices (GSI; [gonad weight/body weight]*100). For each female the stage of ovarian development was classified as immature or resting, developing, mature, or spent (Williams and Bonner, 2006). Measurements of oocyte diameter were taken from the female with the highest GSI each month. Oocytes were separated from surrounding tissue by vigorous shaking in a vial containing 10% formalin. Once separated oocytes were distributed in a clear plastic dish and the diameters of 100 randomly selected developing and mature oocytes were measured to the nearest 0.05 mm along their longest axis using an ocular micrometer and dissecting microscope. To estimate clutch size, total number of mature oocytes were counted in 10 reproductively mature females in April, when GSI values were the greatest. For diet analyses alimentary tracts were removed from three randomly selected individuals each month. Contents from the stomach to the first loop of the intestine were identified to the lowest practical taxon and enumerated using a dissecting microscope. Gut contents were separated into four broad categories (algae, sediment/detritus, terrestrial insects, and aquatic invertebrates) and percent occurrence was calculated for each.

RESULTS

Occurrence and abundance data were obtained for 22 streams and stream reaches within the reported range of Texas Shiner (Table 1). Texas Shiner is possibly extirpated in 14% ($n = 3$) of streams or stream reaches (San Gabriel River, Barton Creek, and upper San Antonio River). It is rare in 18% ($n = 4$) of stream reaches, including three main stem river reaches (Llano River, lower San Antonio River, Rio Grande-Del Rio to San Ygnacio) and one tributary stream (Live Oak Creek). Otherwise, contemporary relative abundances of Texas Shiner are categorized as occasional to frequent in 68% ($n = 15$) of streams and stream reaches.

Based on 1191 fish measured, modal class progression analysis suggested that the Texas Shiner population consisted of 4 y classes (2002 to 2005) from October 2003 to July 2005. Year classes 2002 and 2003 persisted into their third summer (age 2) and were no longer detectable before October of the 3rd y (Fig. 2). During reproductive season (February–October), breeding individuals consisted primarily of age-1 fish: year class 2003 in July 2004 and year class 2004 in July 2005. Age-0 fish (year classes 2004 and 2005) were first captured in the July collections. Mean total lengths (±1 SD) of age-0 fish were 43.6 (4.6) for 2004 year class and 44.4 (10.8) for 2005 year class. Mean total lengths of age-1 fish were 56.8 (2.8) for

TABLE 1.—Historical occurrences and relative abundances for *N. amabilis* with historical population changes within its range

Drainage	Stream or reach	Date of first collection	Relative abundances (%)	Date of relative abundance estimate	Abundance scale	Status	Citation
Brazos	San Gabriel River	1963	0	2010		Possibly extirpated	Labay, 2010
Colorado	North Llano River	1931	37.4	2012	Frequent		Curtis, 2012
	South Llano River	1955	11.7	2012	Occasional		Curtis, 2012
	Llano River	1976	3.7	2012	Rare		Curtis, 2012
	Pedernales River	1951	12.5	2007	Occasional		Shattuck, 2010
	Live Oak Creek	1998	0.3	2007	Rare		Shattuck, 2010
	Barton Creek	1884	0	2011		Possibly extirpated	Labay *et al.*, 2011
Guadalupe	Cypress Creek	1952	21.8	2007	Occasional		Bean *et al.*, 2007
	Blanco River	1965	14.3	2007	Occasional		Bean *et al.*, 2007
	Upper San Marcos River	1938	7.7	2015	Occasional	Stable	Kollaus *et al.*, 2015
	Lower San Marcos River	1882–1891	7.8	2010	Occasional	Increasing	Perkin and Bonner, 2011
	Comal River	1882–1891	6.6	2015	Occasional		THB, unpubl.
	Upper Guadalupe River	1938	10.48	2011	Occasional	Increasing	Perkin and Bonner, 2011
	Lower Guadalupe River	1952	7.39	2011	Occasional	Increasing	Perkin and Bonner, 2011
San Antonio	Upper San Antonio River	1891	0	2014		Possibly extirpated	Craig *et al., in review*
	Lower San Antonio River	1960	0.02	2006	Rare	Stable	Runyan, 2007
Nueces	Upper Nueces	1851	31	2015	Frequent		CAC and THB, unpubl.
Pecos	Indepedence Creek	1963	30.4	2005	Frequent	Stable	Bonner *et al.*, 2005
	Pecos River	1853–1858	6.7	2004	Occasional		Cheek and Taylor, 2015
Rio Grande	Devils River	1851–1854	17.8	2012	Occasional		Kollaus and Bonner, 2012
	Pinto Creek	1938	16.9	2004	Occasional		Garrett *et al.*, 2004
	Rio Grande - Del Rio to San Ygnacio	1954	3.65	1990	Rare		Platania, 1990

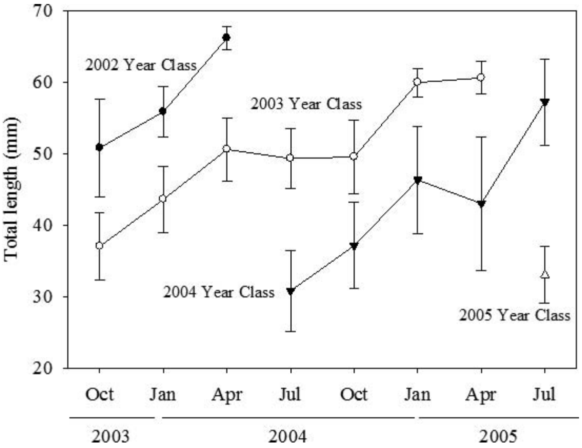

FIG. 2.—Monthly mean total length (±SD) for age-0, age-1, age-2 *N. amabilis* collected from the Blanco River, Texas from October 2003–July 2005

2003 year class and 60.5 (2.2) for 2004 year class. The largest Texas Shiner taken was an age-2, 70 mm fish.

A total of 353 Texas Shiners were analyzed for reproductive condition. Mature ovaries were present in three of fourteen females collected in October 2003. All ovaries were classified as immature or resting in individuals collected in November and December 2003. Gonadal recrudescence in Texas Shiners began as early as January 2004 when 24% of females collected contained developing ovaries. Mature ovaries first appeared in February (17% of females). By April 75% of female Texas Shiners contained mature ovaries. From May to July, mature ovaries were found in 25 to 31% of females. Reproduction peaked again in August and September 2004 when 86% and 71% of females, respectively, contained mature ovaries. Trends in female GSI values corresponded with trends in ovarian development. Mean female GSI value for Texas Shiners were <3% from October 2003 to January 2004, increased to 3.8% in February and 5.9% in March, and peaked in April (GSI = 7.0%). Mean GSI values then decreased by early summer to 3.8% in July before a second smaller peak in August (GSI = 5.2%) and September (GSI = 4.6%) (Fig. 3). Clutch size ranged from 102 to 286 with a mean (±SD) of 174.5 (62.2). Clutch size was positively correlated with fish size (intercept = 1.03, slope = 0.023, $P < 0.01$, $r^2 = 0.74$). Oocyte diameters ranged from 0.15 to 1.2 mm in diameter. Individuals with mature ovaries ($\geq$0.8 mm) exhibited a multimodal distribution suggesting development of multiple cohorts throughout the reproductive season and mature ovaries were present in females from February to October (Fig. 4).

Alimentary tracts of 36 individuals were examined for diet analysis. Food items were present in 31 (86%) Texas Shiner guts examined. Common food items were aquatic insects (71% occurrence) and algae (61%). Among aquatic insects, Ephemeroptera were the most abundant (31% of insects) followed by Trichoptera (26%), Diptera (22%), Coleoptera (12%), and Lepidoptera (4%) (Fig. 5). Terrestrial insects were found in 6% of guts and comprised 5% of all insect taxa identified. Sediment and detritus, perhaps incidentally ingested with other food items, were found in 13% of all Texas Shiners examined.

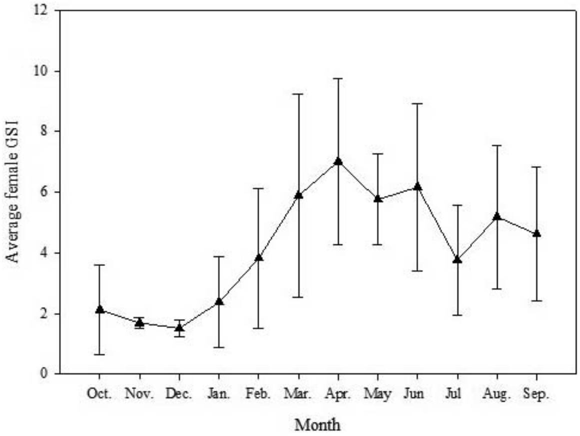

FIG. 3.—Average female gonadosomatic index (GSI) values for *N. amabilis* collected from the Blanco River, Texas from October 2003 to September 2004

DISCUSSION

Populations of Texas Shiners were temporally stable or increasing in six streams or stream reaches (Bonner *et al.,* 2005; Runyan, 2007; Perkin *et al.,* 2010; Kollaus *et al.,* 2015) with abundances categorized as occasional (7 to 22% in relative abundances) to frequent (30 to 37%) in 10 other streams or stream reaches among five drainages (Colorado River, Guadalupe River, San Antonio River, Nueces River, Pecos River, and Rio Grande). Texas Shiners are not reported recently in three streams or stream reaches. Lack of recent collection in the San Gabriel River (Brazos River drainage) might be attributed to extirpation events or incorrect listing of the Brazos River drainage as part of Texas Shiner's range. Historical occurrences of Texas Shiners in the Brazos River drainage are under review by others (Hendrickson and Cohen, pers. comm.). Lack of recent collection of Texas Shiners and other native fishes in urbanized Barton Creek (Colorado River drainage) is associated with instream and downstream dams and nonnative fishes (Labay *et al.,* 2011). However, other spring-associated fishes (*e.g.,* native *Etheostoma lepidum* and nonnative *Astyanax mexicanus*) persist in Barton Creek. Texas Shiners were reported in the upper San Antonio River, another urbanized stream reach, as recent as 2000 (Edwards *et al.,* 2001), but specimens were not taken in 2012 to 2013 (Craig and Bonner, *in review*). Upper San Antonio River has long history of water quality and water quantity concerns, along with nonnative species introductions. Despite two possible extirpation events in urban streams and possibly a third in a Brazos River drainage, populations of Texas Shiner temporally persist with occasional and frequent abundances among multiple and independent streams, stream reaches, and drainages. Therefore, we conclude the conservation status of the Texas Shiner is currently secure.

Predictions of a protracted reproductive season (February to October, 9 mo) and a short life span were supported. In addition female Texas Shiners produce multiple cohorts of oocytes, suggesting multiple spawning events within a season. The 9 mo reproductive season for Texas Shiners in the Blanco River is considered protracted in comparison to latitudinal trends (5.5 mo; Gotelli and Pyron, 1991) and to its closest phylogenetic relatives Rio Grande Shiner (Sublette *et al.,* 1990, Hoagstrom and Brooks, 2005), Emerald Shiner (Carlander,

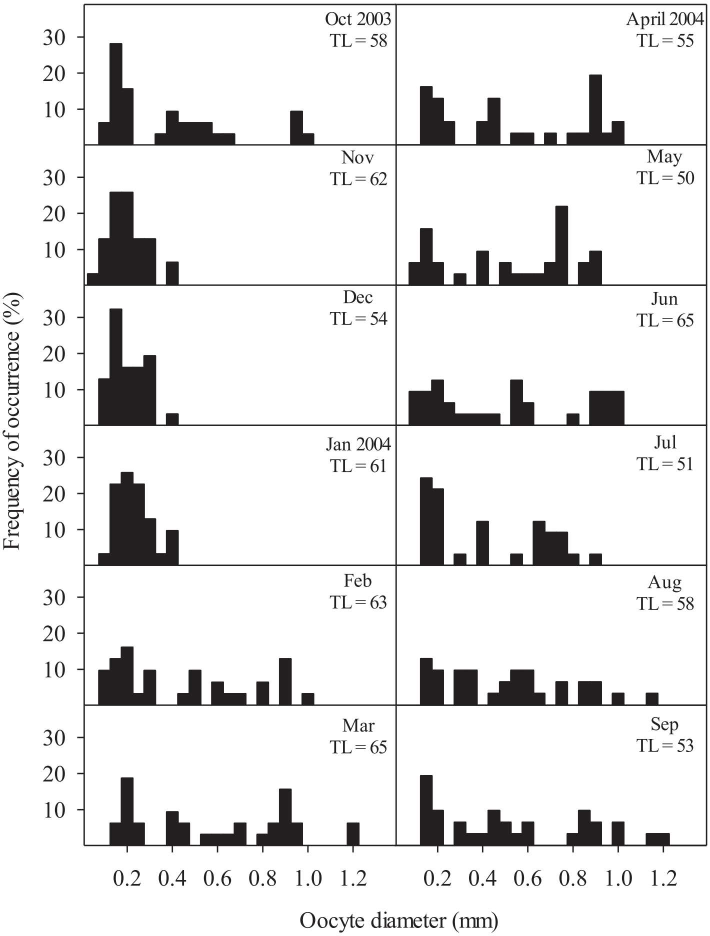

FIG. 4.—Oocyte diameter frequency of occurrence (%) distributions (n = 100 from individual *N. amabilis* females with the greatest gonadosomatic index collected each month from October 2003 to September 2004 from the Blanco River, Texas

1969) and Sharpnose Shiner (Durham, 2007), whose reproductive seasons range from 2 to 3 mo. A protracted reproductive season of 9 mo is similar to other species associated with spring complexes of the Edwards Plateau, such as 10 mo for Ironcolor Shiner *Notropis chalybaeus* (Perkin *et al.,* 2012), 12 mo for Largespring Gambusia *Gambusia geiseri* (Hubbs, 1998), 12 for Leon Springs Pupfish *Cyprinodon bovinus* (Kennedy, 1977); and 11 to 12 mo for Fountain Darter *Etheostoma fonticola* (Schenck and Whiteside, 1977; Nichols, 2015). Protracted reproductive seasons among a phylogenetically diverse community of fishes are attributed to loss of terminating spawning cues associated with stenothermal water temperatures of spring systems (Hubbs, 1985). Whether protracted reproductive seasons are physiological responses or selected adaptions to spring environments is unknown; nevertheless, reproductive efforts among spring-associated fishes are explicitly linked to the spring environments. Texas Shiners have multiple spawning events and a short life span

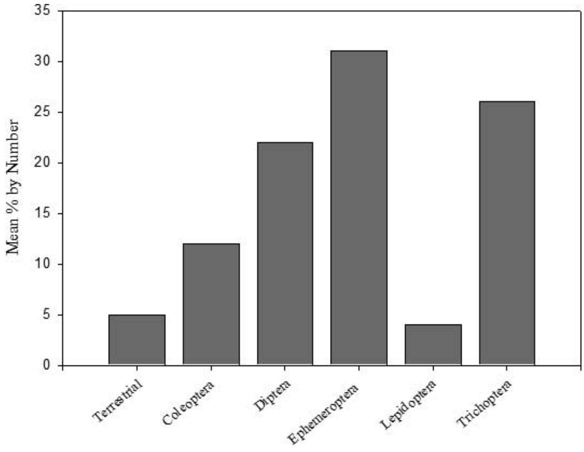

FIG. 5.—Mean percent by number of various aquatic invertebrates identified from alimentary tracts of 36 *N. amabilis* collected from the Blanco River, Texas from October 2003 through July 2005

similar to that of other spring-associated fish (Perkin *et al.,* 2012; Nichols, 2015) and fishes outside of spring complexes in more variable environments (Heins and Rabito, 1986; Durham, 2007). Durham (2007) suggests multiple clutches was a type of "bet-hedging" used by fishes in variable environments to give the best chance at passing on genes. However, Texas Shiner and other fishes found in stable environments, also produce multiple clutches within a spawning season. Future studies are needed to confirm if multiple clutch spawning is a basal ancestral trait or analogously derived under different environmental conditions.

Our prediction on Texas Shiner's feeding strategy was supported. Food habits of Texas Shiners consist primarily of invertebrates and are similar to that of Sharpnose Shiner (Marks *et al.,* 2001), although Texas Shiners more frequently consumed algae (61%) than Sharpnose Shiners (7%; labeled as plant material) and Texas Shiners less frequently consumed detritus, sand, and silt (13%) than Sharpnose Shiners (29% abundance by weight; Marks *et al.,* 2001). Greater algae consumption by the Texas Shiner could be contributed to the Blanco River being less turbid (2.9 NTU; Bean *et al.,* 2007) than the Brazos River (22 to 262 NTU; Ostrand and Wilde, 2002). Elevated turbidity restricts growth of algae (Wang, 1974); therefore, algae availability in Blanco River is likely greater than the Brazos River. Consumption of detritus, sand, and silt in both species could be incidental (Wilde *et al.,* 2001). Alternatively, infrequent consumption of low nutrient food items (*i.e.,* detritus, sand, and silt) by Texas Shiner could also be attributed to greater prey discrimination. Energy devoted to eyes and the neural processing of visual information are greater at lower turbidity levels than greater turbidity levels (Huber and Rylander, 1992; Huber *et al.,* 1997; Kotrschal *et al.,* 1998; Remmington, 2008) with some exceptions (Dugas and Franssen, 2012). Eyes are larger in Texas Shiner than Emerald Shiner, Rio Grande Shiner, and Sharpnose Shiner (Hubbs *et al.,* 2008). Associated with larger eyes, Texas Shiners have a greater mean optic lobe width to total length percentage (3.2%) than Emerald Shiner (2.5%) and a greater mean optic lobe length to total length percentage (4.1%) than Emerald Shiner (3.3%) (Huber and Rylander, 1992; Rio Grande Shiner and Sharpnose Shiner were not quantified). As such greater visual acuity (*e.g.,* greater eye size, larger optic lobes) and related successful feeding could be an adaptation to the commonly clear waters of spring complexes and another explicit link, along with protracted reproductive seasons, between spring-associated fishes and spring environments. However, morphometry of other spring fishes compared to their nonspring associated sister taxa are not reported at this time in order to assess ubiquity of vision acuity.

Although exact mechanisms on why spring-associated fishes do not frequently live outside of spring complexes are still unknown, current literature suggests spring-associated fishes, like the Texas Shiner, are dependent on spring flows. The Edwards Plateau region is rapidly increasing in population (Kollaus and Bonner, 2015). Increases in impervious cover and groundwater extraction, due to urbanization, have contributed to cessation of flows in small springs and decreased base flows in large springs within the Edwards Plateau (Zektser *et al.,* 2005, Sung and Li, 2010), and over-extraction of spring water can contribute to declines in spring fishes within the Edwards Plateau (Winemiller and Anderson, 1997, Craig *et al.,* 2016. Extirpations of Texas Shiners in its range are likely caused by habitat degradation and are coupled with losses of other spring associated taxa (Labay *et al*., 2011; Craig and Bonner*, in review)*. Although we consider current populations as stable, future conservation of Texas Shiner, and other spring fishes of the Edwards Plateau, will coincide with the quantity and quality of spring flow at spring complexes that it inhabits. Therefore, management of spring flows should consider habitat requirements of spring-associated species.

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LITERATURE CITED

Bean, P.T., T.H. Bonner, and B.M. Littrell. 2007. Spatial and temporal patterns in the fish assemblage of the Blanco River. *Texas J Sci.*, **59**:179.

Bielawski, J.P. and J.R. Gold. 2001. Phylogenetic relationships of cyprinid fishes in subgenus Notropis inferred from nucleotide sequences of the mitochondrially encoded cytochrome b gene. *Copeia,* **3**:656–667.

Bonner, T.H., C. Thomas, C.S. Williams, J.P. Karges, and D. Propst. 2005. Temporal assessment of a west Texas stream fish assemblage. *Southwest Nat.*, **50**:74–78.

Carlander, K. 1969. Handbook of Freshwater Fishery Biology. 1st ed. Ames, Iowa: Iowa State University Press.

Cheek, C.A. and C.M Taylor. 2015. Salinity and geomorphology drive long-term changes to local and regional fish assemblage attributes in the lower Pecos River, Texas. *Ecol Freshw Fish.*,

Coburn, M. 1982. Anatomy and Relationships of *Notropis athernoidies.* Ph.D. Dissertation, The Ohio State University. 384 p.

Conner, J.V. and R.D. Suttkus. 1986. Zoogeography of freshwater fishes of the western Gulf Slope of North America. p. 413–456 *In*: Hocutt C.H. and E.O. Wiley (eds.) Zoogeography North American Freshwater fishes. New York: John Wiley and Sons.

Craig, C.A. and T.H. Bonner. In review. Historical perspectives of a fish community within an urban stream. *Urban Ecosyst.,* In review.

———, K.A. Kollaus, K.P. Behen, and T.H. Bonner. 2016. Relationships among spring flow, habitats, and fishes within evolutionary refugia of the Edwards Plateau. *Ecosphere,* **7**:2.

Curtis, S. 2012. Effects of dry baseflow conditions in a declining hydrograph on instream habitats and fish communitites in a semi-arid karstic stream. M.S. Thesis, Texas State University, 41 p.

Dugas, M.B. and N.R. Franssen. 2012. Red shiners (*Cyprinella lutrensis*) have larger eyes in turbid habitats. *Can J Zool.*, **12**:1431–1436.

Durham, B. 2007. Reproductive ecology, habitat associations, and population dynamics of two imperiled cyprinids in a great plains river. Ph.D dissertation, Texas Tech University. 164 p.

Echelle, A.A. and A.F. Echelle. 1978. The Pecos River Pupfish, Cyprinodon pecosensis n. sp. (Cyprinodontidae), with Comments on Its Evolutionary Origin. *Am Soc Ichthyol Herpetol.*, **4**:569–582.

Garrett, G.P., R.J. Edwards, and C. Hubbs. 2004. Discovery of a new population of Devils River minnow (*Dionda diaboli*), with implications for conservation of the species. *Southwest Nat.*, **49**:435–441.

———, C. Hubbs, and R.J. Edwards. 2002. Threatened fishes of the world : *Dionda diaboli* Hubbs & Brown, 1956 (Cyprinidae). *Environ Biol Fishes,* **4**:478–478.

Goldstein, R.M. and T.P. Simon. 1999. Toward a united definition of guild structure for feeding ecology of North American freshwater fishes. p. 123–202 *In*: Goldstein R.M. (ed). Assessing Sustainability Biological Integrity of Water Resources Using Fish Communities. Boca Raton, Florida: CRC Press.

Gayanilo, F.C., P. Sparre, and D. Pauly. 2005. FAO-ICLARM stock assessment tools II. Rome, Italy: FAO; p. 52–71.

Gotelli, N. and Pyron M. 1991. Life history variation in North American freshwater minnows: effects of latitude and phylogeny. *Oikos.* **62**:30–40.

Heins, D.C. and F.G. Rabito. 1986. Spawning performance in North American minnows: direct evidence of the occurrence of multiple clutches in the genus *Notropis. J Fish Biol.*, **28**:343–357.

Hoagstrom, C.W. and J.E. Brooks. 2005. Distribution and status of Arkansas River shiner *Notropis girardi* and Rio Grande shiner *Notropis jemezanus*, Pecos River, New Mexico. *Texas J Sci.*, **57**:35–58.

Hubbs, C. 1985. Darter Reproductive Seasons. *Am Soc Ichthyol Herpetol.*, **1985**:56–68.

———. 1998. Large spring gambusia (*Gambusia geiseri*) produces young in all seasons. *Texas J Sci.*, **50**:343–344.

———, R.J. Edwards, and G.P. Garrett. 2008. An Annotated Checklist of the Freshwater Fishes of Texas, With Keys to Identification of Species. *Texas Acad Sci.* Retrieved October 18, 2016 http://www.texasacademyofscience.org/.

Huber, R. and M.K. Rylander. 1992. Brain morphology and turbidity preference in *Notropis* and related genera (Cyprinidae, Teleostei). *Environ Biol Fishes.*, **33**:153–165.

———, M.J. Van Staaden, L.S. Kaufman, and K.F. Liem. 1997. Microhabitat use, trophic patterns, and the evolution of brain structure in African Cichlids. *Brain Behav Evol.*, **50**:167–182.

Kennedy, S.E. 1977. Life History of the Leon Springs Pupfish, *Cyprinodon bovinus. Am Soc Ichthyol Herpetol.*, **1**:93–103.

Kent, M and P. Coker. 1992. Vegetation description and data analyses: a practical approach. 2nd ed. Wiley-Blacwell. 428 p.

Kollaus, K.A., K.P. Behen, T.C. Heard, T.B. Hardy, and T.H. Bonner. 2015. Influence of urbanization on a karst terrain stream and fish community. *Urban Ecosyst.*, **18**:293–320.

——— and T.H. Bonner. 2012. Habitat associations of a semi-arid fish community in a karst spring-fed stream. *J Arid Environ.*, **76**:72–79.

Kotrschal, K., M.J. Van Staaden, and R. Huber. 1998. Fish brains: Evolution and environmental relationships. *Rev Fish Biol Fish,* **8**:373–408.

Labay, B. 2010. The influence of land use, zoogeographic history, and physical habitat on fish community diversity in the lower brazos watershed. M.S. Thesis, Texas State University, 70 p.

———, A.E. Cohen, B. Sissel, D.A. Hendrickson, F.D. Martin, and S. Sarkar. 2011. Assessing historical fish community composition using surveys, historical collection data, and species distribution models. *PLoS One,* **6**:e25145.

Marks, D.E., G.R. Wilde, K.G. Ostrand, and P.J. Zwank. 2001. Foods of the smalleye shiner and sharpnose shiner in the upper brazos river, texas. *Texas J Sci.*, **4**:327–334.

Nichols, H. 2015. Habitat mediated effects on Etheostoma fonticola reproduction. M.S. Thesis, Texas State University. 35 p.

Ostrand, K.G. and G.R. Wilde. 2002. Seasonal and spatial variation in a prairie stream fish assemblage. *Ecol Freshw Fish,* **11**:137–149.

PERKIN, J.S. AND T.H. BONNER. 2011. Long-term changes in flow regime and fish assemblage composition in the guadalupe and san marcos rivers of texas. *River Res Appl.*, **579**:566–579.

———, Z.R. SHATTUCK, AND T.H. BONNER. 2012. Life History Aspects of a Relict Ironcolor Shiner *Notropis chalybaeus* Population in a Novel Spring Environment. *Am Midl Nat.*, **167**:111–126.

PLATANIA, S.P. 1990. The ichthyofauna of the Rio Grande drainage, Texas and Mexico, from Boquillas to San Ygnacio. U.S. Fish and Wildlife Service. Arlington, TX. 100 p.

REMMINGTON, R.K. 2008. Ecology and Evolution of Turbid Water Adaptations in Fishes. Ph.D. Dissertation, University of Oklahoma. 100 p.

RUNYAN, D.T. 2007. Fish Assemblage Changes in Western Gulf Slope Drainages: An historical Perspective and Distribution and Diet of Larval and Juvenile Fishes In the Rio Grande, Texas. M.S. Thesis, Texas State University, 85 p.

SHATTUCK, Z.R. 2010. Spatiotemporal patterns of fish and aquatic insects in an urbanized watershed of Central Texas. M.S. Thesis, Texas State University, 34 p.

STIERS, I., N. CROHAIN, G. JOSENS, AND L. TRIEST. 2011. Impact of three aquatic invasive species on native plants and macroinvertebrates in temperate ponds. *Biol Invasions.*, **13**:2715–2726.

SUBLETTE, J.E., M.D. HATCH, AND M. SUBLETTE. 1990. The fishes of New Mexico. Albuquerque, New Mexico: University New Mexico Press. 393 p.

SUNG, C.Y. AND M.H. LI. 2010. The effect of urbanization on stream hydrology in hillslope watersheds in central Texas. *Hydrol Process*, **24**:3706–3717.

WANG, W.C. 1974. Effect of turbidity on algal growth. Circular - Illinois State Water Survey, **121**:1–12.

WILLIAMS, C.S. AND T.H. BONNER. 2006. Habitat Associations, Life History and Diet of the Sabine Shiner *Notropis sabinae* in an East Texas Drainage. *Am Midl Nat.*, **155**:84–102.

WINEMILLER, K.O. AND A.A. ANDERSON. 1997. Response of Endangered Desert Fish Populations to a Constructed Refuge. *Restor Ecol.*, **5**:204–213.

ZEKTSER, S., H.A. LOÁICIGA, AND J.T. WOLF. 2005. Environmental impacts of groundwater overdraft: Selected case studies in the southwestern United States. *Environ Geol.*, **47**:396–404.

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