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Persistence of *Etheostoma parvipinne* (Goldstripe Darter) in a Single Tributary on the Periphery of its Range

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Abstract - We report the occurrence of a single population of *Etheostoma parvipinne* (Goldstripe Darter) in a small, acidic, spring-fed stream within the Colorado River drainage following an extended period of below-average precipitation (January–September 2011), a wildland fire (September 2011), and subsequent debris and sediment flows (November 2011–May 2012). Goldstripe Darters were taken from Alum Creek (Bastrop County, TX) along with a cyprinid, a poeciliid, and several species of centrarchids in June 2012. Occurrence of Goldstripe Darters in Alum Creek provides a regional example of fish-community responses to wildland fires. In addition, understanding the mechanism of long-term persistence in a single tributary on the periphery of a species range might offer insight into the origin of endemic fishes and persistence of disjunct fish populations within aquatic evolutionary refugia of central Texas.

Etheostoma parvipinne C.H. Gilbert & Swain (Goldstripe Darter) is broadly distributed throughout the lower Mississippi River drainage, eastern gulf slope drainages to Georgia, and western gulf slope drainages to Texas (Boschung and Mayden 2004). Within Texas, the Goldstripe Darter is distributed among main stems and tributaries of the Red River to Brazos River (Hendrickson and Cohen 2015, Herbert and Gelwick 2003, Hubbs et al. 2008). In the Colorado River, the western-most extent of its western gulf slope distribution, Goldstripe Darter occurs only in a small tributary stream, Alum Creek (Bastrop County, TX; Hendrickson and Cohen 2015). Alum Creek is one of several drainages within a relict *Pinus taeda* L. (Loblolly Pine) forest of central Texas (Al-Rabab'ah and Williams 2004). Soils of the Alum Creek watershed are composed primarily of sands and clays of the Eocene Reklaw Formation and Queen City Sand units (US Geological Survey 2015). Groundwater sources within localized areas of the Reklaw Formation are acidic (Hayes 1988) and contain large concentrations of sulfates ("Alum-like taste"; Follett 1970). Within Alum Creek, groundwater supports perennially flowing springs (i.e., Alum springs; Follett 1970), providing base flow (1.2 L/s; Brune 1981), but water present is sometimes reduced to pools (G. Creacy, Texas Parks and Wildlife Department Regional Natural Resources/Wildland Fire Coordinator, Bastrop, TX, 31 January 2012 pers. comm.). In addition to the Goldstripe Darter, *Etheostoma gracile* (Girard) (Slough Darter) is reported in the Alum Creek (Hendrickson and Cohen 2015); otherwise, to the best of our knowledge, other fish occurrences and their abundances are not reported for this creek.

In 2011, Alum Creek watershed experienced an unusual series of climatic and landscape events. The watershed and surrounding region received less than average precipitation from January through October 2011 (235 mm of rain; normal rainfall totals: 800 mm, 1981–2010; Smithville Texas Climate Station). In September 2011, the Bastrop County Complex Wildfire burned 13,354 ha (33,000 ac) of relict pine forest with a mix of severity levels, ranging up to heavily burned (USDI National Park Service 2003), and burned through the Alum Creek riparian corridor and associated uplands. Following the fire, rainfall totals (605 mm)

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were similar to normal totals (535 mm) between November 2011 and May 2012. Percent of days with rain was 22%, averaging 14.5 mm per day and with a maximum daily total of 75 mm. Alum Creek consisted only of pool habitats for several months before the fire, exposed to streamside burning during the fire and inundated with sediments, ash, and debris flow after the fire. Goldstripe Darters likely persisted in Alum Creek during drier periods (i.e., 1950s drought of record; McGregor 2015) based on previously recorded collections (Hendrickson and Cohen 2015) but without subsequent effects of fire and debris flow. In a review of published studies, Dautreuil (2013) reported that fish mortalities, extirpations, and decreases in fish densities occurred in 7 of 9 studies immediately following a fire, precipitations events, and subsequent sediment, ash, and debris flows within streams. Given that fishes are susceptible to stream drying (Capone and Kushlan 1991) and fire effects (Dautreuil 2013), the purpose of our study was to confirm that Goldstripe Darter continue to exist within Alum Creek, the only population from the Colorado River and its farthest west population.

Two sites were sampled on Alum Creek in June 2012. The lower site (Site 1) was located immediately upstream from the Texas State Highway 71 crossing (30°4'5.15"N, 97°13'8.82"W), which is 7 km upstream from Alum Creek's confluence with the Colorado River. The upper site (Site 2) was located 3.5 km upstream of Site 1 at the Park Road 1C crossing (30°5'46.99"N, 97°13'12.20"W). Fish were taken from available habitats (i.e., riffle, run, and pools) from a downstream-to-upstream direction within a 300-m stream section at both sites. In flowing-water habitats (i.e. riffle and run), we placed a block seine (1.2 m by 1.8 m, mesh size = 3.2 mm) at the downstream end of a habitat and utilized a single pass with a backpack electroshocker (Smith-Root Model 12-B POW), with 2 netters capturing stunned fish with dip nets or guiding stunned fishes into the block seine. In pool habitats, we made a single pass with a backpack shocker, followed by multiple passes with the seine until fish were not taken in 2 consecutive seine hauls. Fish collection was conducted under the authorization of Texas Parks and Wildlife Scientific Collecting Permit SPR-0601-159 and Texas State University IACUC Protocol 0530-0620-15.

At Site 1, habitats ranged 0.2–0.3 m in depth, 2.0–5.5 m in width, and 0.0–0.2 cm/s in current velocity, and consisted of sand (75%), gravel (15%), and cobble (10%) substrates. At Site 2, habitats ranged 0.1–0.5 m in depth, 2–15 m in width, and 0.01–0.17 cm/s in current velocity and consisted of sand (90%), silt (7%), and gravel (3%) substrates. Water temperature was 24 °C, and pH was 4.0 at both sites. Riparian vegetation was scorched but intact at both sites. Upland vegetation at Site 1 was heavily burned resulting in high mortality of the dense tree stand. Upland vegetation at Site 2 consisted of a dense stand of Loblolly Pine, ranging in fire severity between lightly burned to heavily burned.

Seven species of fishes were taken from Alum Creek: 6 species (n = 30 individuals) from Site 1 and 3 species (n = 12) from Site 2. Juvenile *Micropterus salmoides* (Lacépède) (Largemouth Bass) was the most abundant species (77%) at Site 1, followed by *Lepomis cyanellus* Rafinesque (Green Sunfish) (10%), *Notemigonus crysoleucas* (Mitchill) (Golden Shiner) (3%), *Gambusia affinis* (S.F. Baird & Girard) (Western Mosquitofish) (3%), *L. macrochirus* Rafinesque (Bluegill) (3%), and *L. microlophus* (Günther) (Redear Sunfish) (3%). Largemouth Bass (all juvenile) was the most abundant species (50%) at Site 2, followed by Redear Sunfish (25%) and Goldstripe Darter (25%).

Goldstripe Darters occurred in Alum Creek, despite a prolonged dry period, fire, and subsequent sediment, ash, and debris flows. Wildland fires followed by run off from burned areas are associated with fish kills through suffocation (e.g., clogging the gills; Bozek and Young 1994), poisoning from pyrogenic toxicants (Barber et al. 2003), and subsequent low dissolved oxygen in the stream (Lyon and Connor 2008). Among the 7 studies reviewed by Dautreuil (2013), fish moralities and downstream displacements of fishes were associated with fish extirpations in 5 streams and lower numbers of fishes in 2 streams following sediment, ash, and debris flows following a fire. Within streams with lower numbers of fishes, resident fishes likely used nearby habitats with lower fire severity to avoid stream habitats with sediment, ash, and debris flows (Burton 2005, Lyon and Conner 2008). Among all streams, complete recolonization by resident fishes occurred 1 to 6 years following sediment, ash, and debris flows. In Alum Creek, Goldstripe Darters and other fishes might have persisted in less-disturbed areas, such as small spring outflows, during and after the fire and debris flows, or recolonized Alum Creek following the fire; however, recolonization by Goldstripe Darters is unlikely, since no other nearby populations are thought to exist.

Goldstripe Darters are rarely restricted to a single tributary within a larger stream system, and their long-term persistence within Alum Creek is an interesting zoogeographical observation. Goldstripe Darters are found among multiple locations within drainages of its native range, though not considered very abundant among sites (Herbert and Gelwick 2003, Lemmons and Pigg 1999, Robinson 1977, Smiley et al. 2006, Winston 2002). Goldstripe Darter's habitat associations within Alum Creek—a small, low-gradient, spring-fed stream with shallow depths, slow currents, and sand to gravel substrates—are similar to those reported elsewhere across its range (Herbert and Gelwick 2003, Lemmons and Pigg 1999, Robison 1977, Smiley et al. 2006). Other Colorado River tributaries downstream from Alum Creek, such as JD Creek (Bastrop County), Pin Oak Creek, and Rabbs Creek (Fayette County), have similar instream habitats but appear to lack Goldstripe Darters, based on limited historical records (Hendrickson and Cohen 2015) and recent collections (V. Dautreuil and T. Bonner, unpubl. data). Likely, Goldstripe Darter's occurrence within Alum Creek is unrelated to an affinity for Loblolly Pine forests, which are often the dominant terrestrial vegetation in streams with Goldstripe Darters (Herbert and Gelwick 2003, Smiley et al. 2006, this study). Goldstripe Darters occur in streams without pine trees in the upland community (Winston 2002) and are not reported in other streams within the relict Loblolly Pine forest of Bastrop County. Rather, Goldstripe Darter occurrence within Alum Creek could be related to a tolerance for the acidity of groundwater and surface flows of the Reklaw Formation and Alum Creek. Another unique population of Goldstripe Darters occurs in an acidic small pond in Rusk County, TX (Neches River drainage; about 300 km east of Alum Creek), supported by groundwater from the same strata layer (i.e., Eocene Reklaw Formation) as Alum Creek (Robbins et al. 2003). Goldstripe Darter is the only fish species found in the acidic pond, which has a pH ranging from 2.9 to 4.0. Lethal acidic thresholds of many species range between pH 4.0 and 5.2 (Alabaster and Lloyd 1982). However, at least 1 species (i.e., *Tribolodon hakonensis* (Günther) [Osorezan Dace]) is adapted to waters with a pH ranging from 3.4 to 3.8 (Hirata et al. 2003). In other distributional reports, Goldstripe Darters are not particularly associated with acidic waters; pH in streams with Goldstripe Darters are slightly acidic (6.1 to 6.5; Robison 1977) or not reported (Lemmons and Pigg 1999, Smiley et al. 2006, Winston 2002). In east Texas, Goldstripe Darters are associated among streams with higher pH (range not given; Herbert and Gelwick 2003).

Goldstripe Darter's persistence within a spring-dependent stream on the periphery of its range shares similarities to the persistence of disjunct fish populations and the origin and persistence of endemic fishes within evolutionary refugia immediately west of the lower Colorado River drainage (Conner and Suttkus 1986). Throughout the Pleistocene and Holocene, plants and animals expanded westward during cooler and wetter periods of glacial extensions and contract eastward during warmer and drier periods of glacial retreats within western gulf slope drainages of Louisiana, Texas, and New Mexico (i.e., retreating edge hypothesis; Al-Rabab'ah and Williams 2004). During interglacial periods, evolutionary refugia, such as spring complexes of the Edwards Plateau of central Texas (Craig et al. 2016), provided aquatic habitats that are highly decoupled from regional climate (Davis et al. 2013). Within the Edwards Plateau, examples of disjunct populations include *Notropis chalybaeus* (Cope) (Ironcolor Shiner) (Perkin et al. 2012) and *Minytrema melanops* (Rafinesque) (Spotted Sucker) (Hubbs et al. 2008), and examples of endemic fishes include *Notropis amabilis* (Girard) (Texas Shiner), *Percina carbonaria* (Baird & Girard) (Texas Logperch), and *Etheostoma fonticola* (Jordan & Gilbert) (Fountain Darter) (Conner and Suttkus 1986). Origins of endemic fishes are thought to be derived from ancestral forms persisting and subsequently radiating in evolutionary refugia (Conner and Suttkus 1986, Craig et al. 2016). However, mechanisms are unclear on initial persistence of ancestral, and later endemic, forms and on persistence of disjunct populations within evolutionary refugia of the Edwards Plateau. Specifically, why do fishes initially associate with evolutionary refugia and what abiotic and biotic factors (e.g., habitat type, species fitness) enable persistence through time? Perhaps Goldstripe Darter is preadapted to acidic conditions, inhabiting water bodies that few other fishes can tolerate (i.e., novel environments), which enables persistence without competition or predation. Similar preadaptations are suspected for catfishes (e.g., nocturnal and chemical-sensory feeding) and their success in surviving and radiating within subterranean environments (Trajano 1997). Thus, Goldstripe Darter's persistence on the periphery of their range attributed to preadaptations of novel spring environments could be similar to the persistence of disjunct fish populations and ancestors and subsequent endemic fishes within novel, stenothermal spring complexes of the Edwards Plateau.

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