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New occurrence records for *Eurycea tonkawae* Chippindale, Price, Wiens & Hillis, 2000 (Caudata, Plethodontidae) from an urbanized watershed in Travis County, Texas, USA

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Abstract

We report two new occurrence records for Jollyville Plateau Salamanders, *Eurycea tonkawae* Chippindale, Price, Wiens & Hillis, 2000, from an urbanized watershed in Travis County, Texas, USA. *Eurycea tonkawae* is listed as federally threatened under the Endangered Species Act of 1973 due to threats from urbanization, including degradation of water quality and quantity. These new records fill a distributional gap within its known range, highlight the importance of surveying historically neglected areas, identify unprotected populations, and encourage the discovery of new populations.

Keywords

Conservation, Edwards Aquifer, habitat, salamander, spring, threatened species, urbanization.

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Introduction

Jollyville Plateau Salamanders, *Eurycea tonkawae* Chippindale, Price, Wiens & Hillis, 2000, are permanently aquatic plethodontid salamanders restricted to groundwater-fed aquatic habitats in Travis and Williamson counties, Texas, USA (Chippindale et al. 2000; Chippindale 2005; Devitt et al. 2019). The entire range of this taxon exists in or near the urban matrix of Austin, Cedar Park, Round Rock, and Georgetown, Texas (Devitt et al. 2019; Fig. 1). *Eurycea tonkawae* relative abundance and density are negatively correlated with development and urbanization (Bowles et al. 2006; Bendik et al. 2014). The specific mechanisms resulting in reduced population sizes have not been identified, but degraded water quality, reduced groundwater quantity, exacerbated flash floods, and changes to the general faunal community are suggested (Bowles et al. 2006; Bendik et al. 2014). In 2013, the U. S. Fish and Wildlife Service (USFWS) listed *E. tonkawae* as federally threatened under the Endangered Species Act of 1973 (USFWS 2013a). This species is additionally considered Critically Imperiled (G1) by NatureServe (2019) and Endangered by the International Union for the Conservation of Nature (IUCN 2019).

Chippindale et al. (2000) formally described *E. tonkawae* as a species. Prior to this description, populations

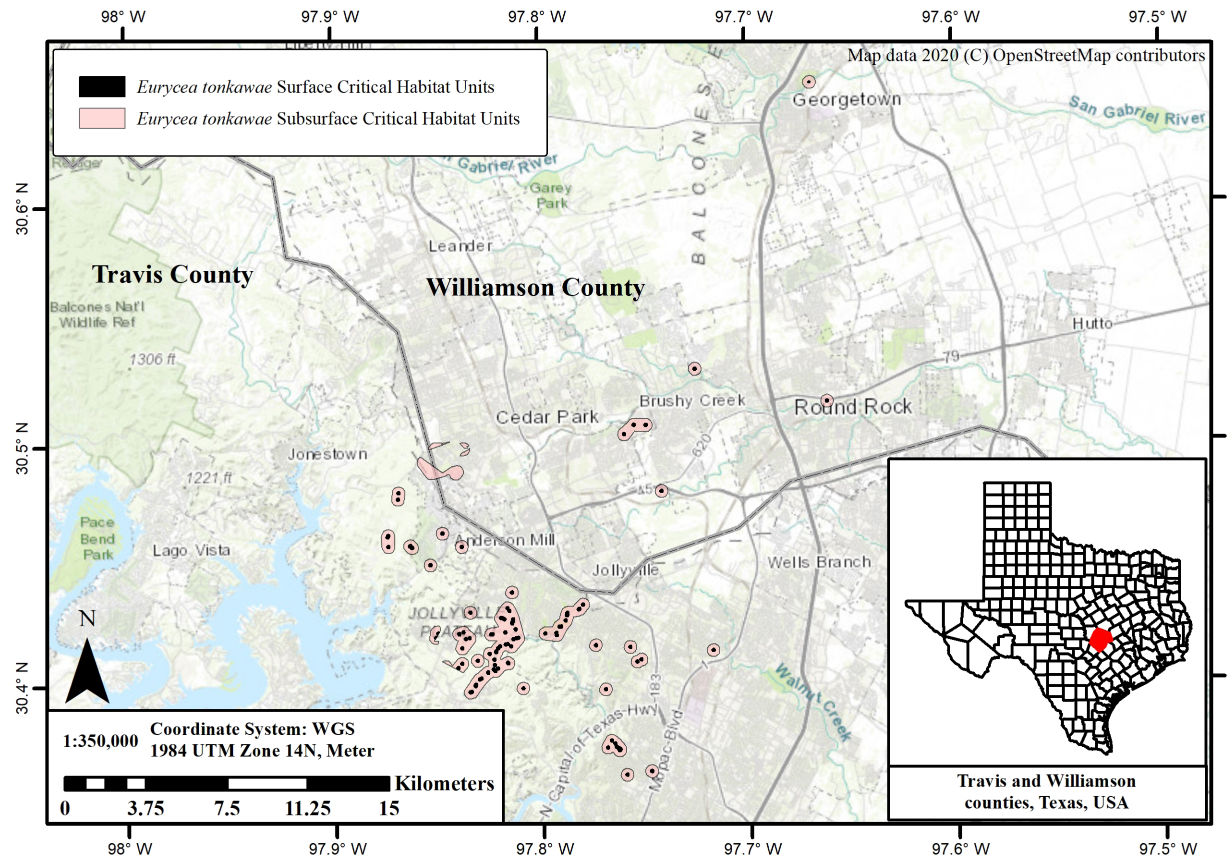

Figure 1. Range of *Eurycea tonkawae* in Travis and Williamson counties, Texas, USA, with known populations and associated U.S. Fish and Wildlife Service critical habitat units (USFWS 2013b) depicted. San Gabriel Springs, the northern–most locality, is a proposed critical habitat unit because this locality was considered *E. naufragia* at the time of critical habitat unit establishment (USFWS 2014a; Devitt et al. 2019). Map data 2020 (C) OpenStreetMap contributors.

within its current range were reported as Texas Salamanders, *E. neotenes* Bishop and Wright, 1937 (Baker 1961; Sweet 1982). The geographic range of *E. tonkawae* remained static for 20 years until Devitt et al. (2019) suggested a taxonomic update that expanded its range 14 km north within Williamson County to include an additional cluster of springs (San Gabriel Springs). Specimens of *E. tonkawae* were first collected at Kreinke Spring and Brushy Creek Spring in Williamson County between 1947 and 1948, and Marshall Ford Dam Spring in Travis County, Texas, in 1961 (Baker 1961). Sweet (1982) provided locality data for four additional populations: three in Travis County and one in Williamson County. Chippindale et al. (2000) included specimens from 17 locations, including 15 previously undocumented populations, in their phylogenetic analyses that resulted in the naming of the taxon. Davis et al. (2001) provided locations for 35 populations, including 22 previously undocumented populations, which brought the number of known populations to 44 in 2001. These 44 sites included the current latitudinal and longitudinal limits of the taxon, and additional sites, primarily within the Bull Creek tributaries, were added over the next 12 years (O'Donnell et al. 2006, 2008; Bendik 2017). During the federal listing process, the USFWS established 32 critical habitat units (Fig. 1) that protected the 106 known surface populations and 16 known subsurface populations (USFWS 2013a, 2013b). Additionally, San Gabriel Springs is a proposed critical habitat unit because this locality was considered to be occupied by Georgetown Salamanders, *E. naufragia* Chippindale, Price, Wiens & Hillis, 2000, at the time of critical habitat unit establishment (USFWS 2014a; Devitt et al. 2019).

Here, we report two new occurrence records for *Eurycea tonkawae* and discuss the geographic distribution, the habitat use, the protection of known populations, and the potential for discovery of new populations of this taxon.

Methods

From December 2018 through July 2019, we surveyed portions of Furtado and Mayfield creeks within the Bull Creek drainage basin in Austin, Texas, USA. *Eurycea* salamanders had not been documented from either of these waterbodies. Mayfield Creek is a tributary of Furtado Creek and is fed by Sobchak Springs which discharge water from the Edwards Aquifer (TWSC 2014). We surveyed Mayfield Creek twice, and both surveys occurred from the Sobchak Springs headwaters to approximately 125 m downstream. We surveyed Furtado Creek eight times and had access to the lower 0.5 km of Furtado

Creek to its confluence with Bull Creek. This section of Furtado Creek does not have a discrete spring, but does contain a stream segment that appears to gain groundwater. We did not have access to Furtado Creek upstream to its confluence with Mayfield Creek. The landscape surrounding both creeks is dominated by urbanization and mixed oak (*Quercus* spp.) and Ashe Juniper (*Juniperus asheii* Buchholz, 1930) woodlands on upper Glenrose limestone (TWSC 2014).

We surveyed for salamanders throughout both creeks, including in areas that are infrequently searched for central Texas *Eurycea*, e.g., greater than 25 m downstream of a spring, culverts, deep pools (but see Bendik et al. 2016). We manually searched for salamanders in and under potential cover objects in accordance with USFWS survey protocol (USFWS 2014b), and we documented survey effort during most events as the time spent searching and the number of searched cover objects. We attempted to capture each observed salamander, and we recorded body and head photographs of captures on a standardized grid background with the salamander alive and in a water-filled dish. We used Wild-ID photographic recognition software to evaluate pigmentation patterns on the salamander's head to identify potentially recaptured individuals (Bolger et al. 2012; Bendik et al. 2013). We measured snout–vent length (SVL) and total length (TL) of all captured salamanders with dial calipers to the nearest 0.1 mm, and we determined gravidity by visually checking for oocytes through the salamander's translucent venter (Gillette and Peterson 2001; Pierce et al. 2014). We recorded habitat parameters during most surveys, including cover object and substrate descriptions as well as water temperature, pH, dissolved oxygen (DO), and conductivity. We measured water conditions with a Com-100 from HM Digital (Culver City, California, USA), EcoTestr pH 2 from Oakton Instruments (Vernon Hills, Illinois, USA), and HI 9147 from Hanna Instruments. We collected genetic samples from all non-vouchered captures following fluid preservation procedures for herpetofauna (Gamble 2014; Simmons 2015). We deposited voucher specimens in the Biodiversity Collections (formerly Texas Natural History Collections; TNHC) at The University of Texas at Austin, Austin, Texas, USA. We conducted all work in accordance with scientific permits from the USFWS (TE37416B-0 and TE833851-0), the Texas Parks and Wildlife Department (SPR-0319-056 and SPR-0113-006), and the City of Austin Balcones Canyonlands Preserve (White-2019 and Bendik-2019).

Results

Eurycea tonkawae (Chippindale, Price, Wiens & Hillis, 2000)

New records. USA • 1 adult; Texas, Travis County, Austin, Furtado Creek; 30.3848°N, 097.7660°W; 199 m a.s.l.; 17 Dec. 2018; KS and NFB leg.; observed under cobble on silt and gravel substrate (Fig. 2A). • 1 adult, gravid female, SVL = 32.9 mm, TL = 62.3 mm; Texas, Travis County, Austin, Mayfield Creek, Steck Valley Greenbelt; 30.3825°N, 097.7584°W; 229 m a.s.l.; 8 Feb. 2019;

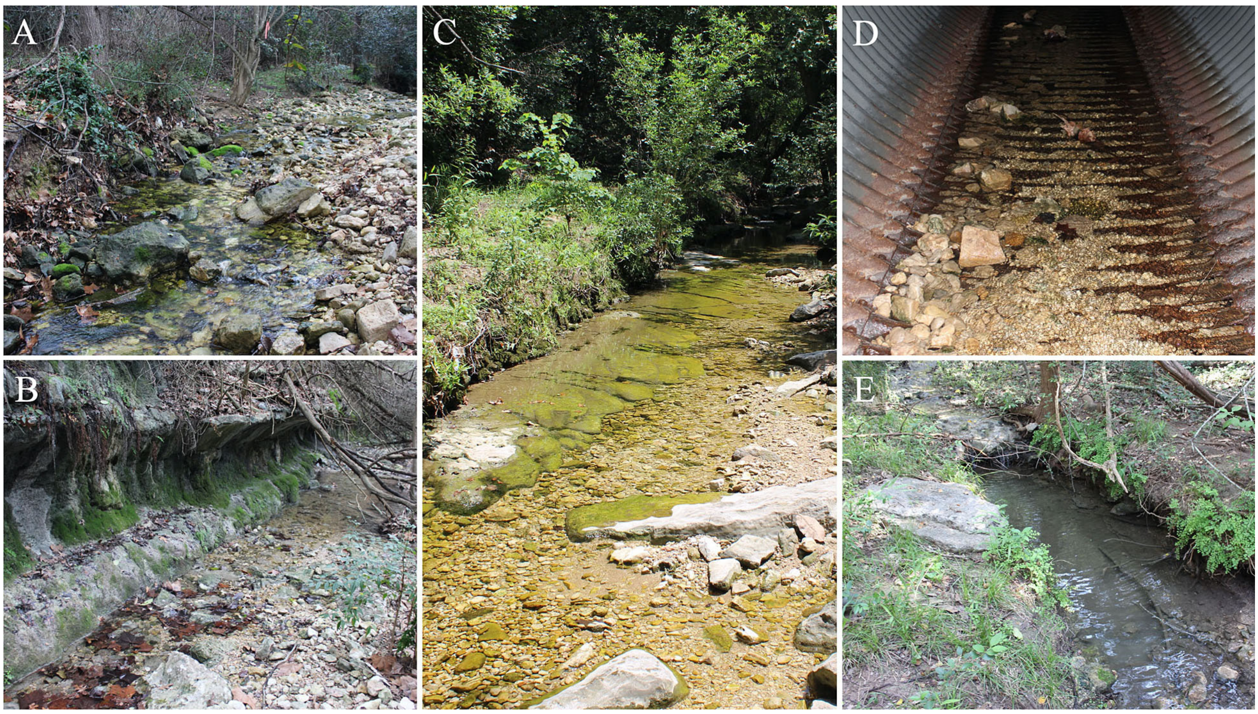

Figure 2. Locations of *Eurycea tonkawae* observations in Austin, Texas, USA. Number of observations per location are provided in parentheses. **A.** Segment of Furtado Creek observed to gain groundwater (*n* = 2). **B.** Mayfield Creek, approximately 50 m downstream of Sobchak Springs in the Steck Valley Greenbelt (*n* = 1). **C.** Furtado Creek in the Bull Creek Greenbelt (*n* = 2). **D.** Furtado Creek flowing through a culvert under Spicewood Springs Road; salamanders were observed in gravel accumulated in culvert corrugations (*n* = 3). **E.** Mayfield Creek, approximately 115 m downstream of Sobchak Springs in the Steck Valley Greenbelt (*n* = 1).

RMJ, KS, NFB, ZCA, Craig Crawford, and KW leg.; collected under cobble on gravel substrate approximately 50 m downstream of the nearest spring outlet (Fig. 2B), water depth = 5 cm, temperature = 12.3 °C, pH = 7.7, DO = 7.8 mg/L, conductivity = 899 μS/cm; collected photographs and tissue sample. • 1 subadult, SVL = 21.5 mm, TL = 38.0 mm; Texas, Travis County, Austin, Furtado Creek, Bull Creek Greenbelt; 30.3840°N, 097.7673°W; 193 m a.s.l.; 4 Jun. 2019; AL, ZCA, and RMJ leg.; collected under cobble on bedrock substrate (Fig. 2C), water temperature = 22.8 °C, pH = 7.6, conductivity = 772 μS/cm; collected photographs and tissue sample. • 1 adult, SVL = 35.4 mm, TL = 66.0 mm; Texas, Travis County, Austin, Furtado Creek; 30.3842°N, 097.7668°W; 196 m a.s.l.; 4 Jun. 2019; AL, ZCA, and RMJ leg.; collected in gravel deposits in the corrugations of a metal culvert pipe beneath Spicewood Springs Road (Fig. 2D), water temperature = 22.8 °C, pH = 7.6, DO = 6.0 mg/L, conductivity = 772 μS/cm; collected photographs and tissue sample. • 2 adults, SVL = 30.4 mm, TL = 57.8 mm and SVL = 32.0 mm, TL = 51.5 mm; Texas, Travis County, Austin, Furtado Creek; 30.3843°N, 097.7666°W; 197 m a.s.l.; 4 Jun. 2019; ZCA, AL, and RMJ leg.; collected in gravel deposits in the corrugations of a metal culvert pipe beneath Spicewood Springs Road (Fig. 2D), water temperature = 22.8 °C, pH = 7.6, conductivity = 772 μS/cm; collected photographs and tissue samples. • 1 adult, SVL = 24.7 mm, TL = 46.1 mm; Texas, Travis County, Austin, Furtado Creek, Bull Creek Greenbelt; 30.3840°N, 097.7673°W; 193 m a.s.l.; 20 Jun. 2019; ZCA, ARM, RMJ, and AL leg.; collected under cobble on bedrock substrate (Fig. 2C), water temperature = 24.9 °C, pH = 7.5, conductivity = 690 μS/cm; collected photographs and tissue sample. • 1 adult, SVL = 29.5 mm, TL = 56.0 mm; Texas, Travis County, Austin, Furtado Creek; 30.3848°N, 097.7660°W; 199 m a.s.l.; 20 Jun. 2019; AL, RMJ, ARM, and ZCA leg.; collected under cobble on silt and gravel substrate (Fig. 2A), water temperature = 24.9 °C, pH = 7.4, DO = 4.6 mg/L, conductivity = 683 μS/cm; whole specimen vouchered, TNHC 113344 (Fig. 3). • 1 adult, SVL = 26.5 mm, TL = 46.3 mm; Texas, Travis County, Austin, Mayfield Creek, Steck Valley Greenbelt; 30.3830°N, 097.7582°W; 226 m a.s.l.; 20 Jun. 2019; ARM, AL, RMJ, and ZCA leg.; collected under cobble on silt, gravel, and bedrock substrate approximately 115 m downstream of the nearest spring outlet (Fig. 2E), water temperature = 24.1 °C, pH = 7.1, DO = 4.3 mg/L, conductivity = 811 μS/cm; whole specimen vouchered, TNHC 113345. See Figure 4 for a distribution map of new records.

We detected seven *E. tonkawae* in Furtado Creek; two were near a gaining segment in the creek bed (Fig. 2A), and the remaining five were 50–100 m downstream of this location in areas without noticeable groundwater input. We quantified survey effort during six of our eight site visits which totaled 991 person minutes and 9,745 searched cover objects to detect six salamanders. We did not detect salamanders during five of our eight Furtado Creek survey events. We detected two *E. tonkawae* in Mayfield Creek; one during each survey. We quantified survey effort on 20 June 2019 and spent 260 person minutes and searched 1,694 cover objects to find one salamander. We vouchered one specimen from each creek, and we collected photographs and tissue samples from all other captures. All of the captures from both creeks were unique individuals, i.e., we did not recapture any animals.

Identification. These specimens are assignable to the Septentriomolge clade of central Texas *Eurycea* given their occurrence north of the Colorado River (Hillis et al. 2001). In the absence of genetic characterization, we identified these animals as *E. tonkawae* because they generally demonstrated the morphology of this taxon as

Figure 3. *Eurycea tonkawae* voucher TNHC 113344 collected on 20 June 2019 in Furtado Creek, Austin, Texas, USA. This specimen demonstrates the general pattern and coloration of all nine *Eurycea tonkawae* observations in Furtado and Mayfield Creeks, Austin, Texas, USA. Scale bar = 10 mm.

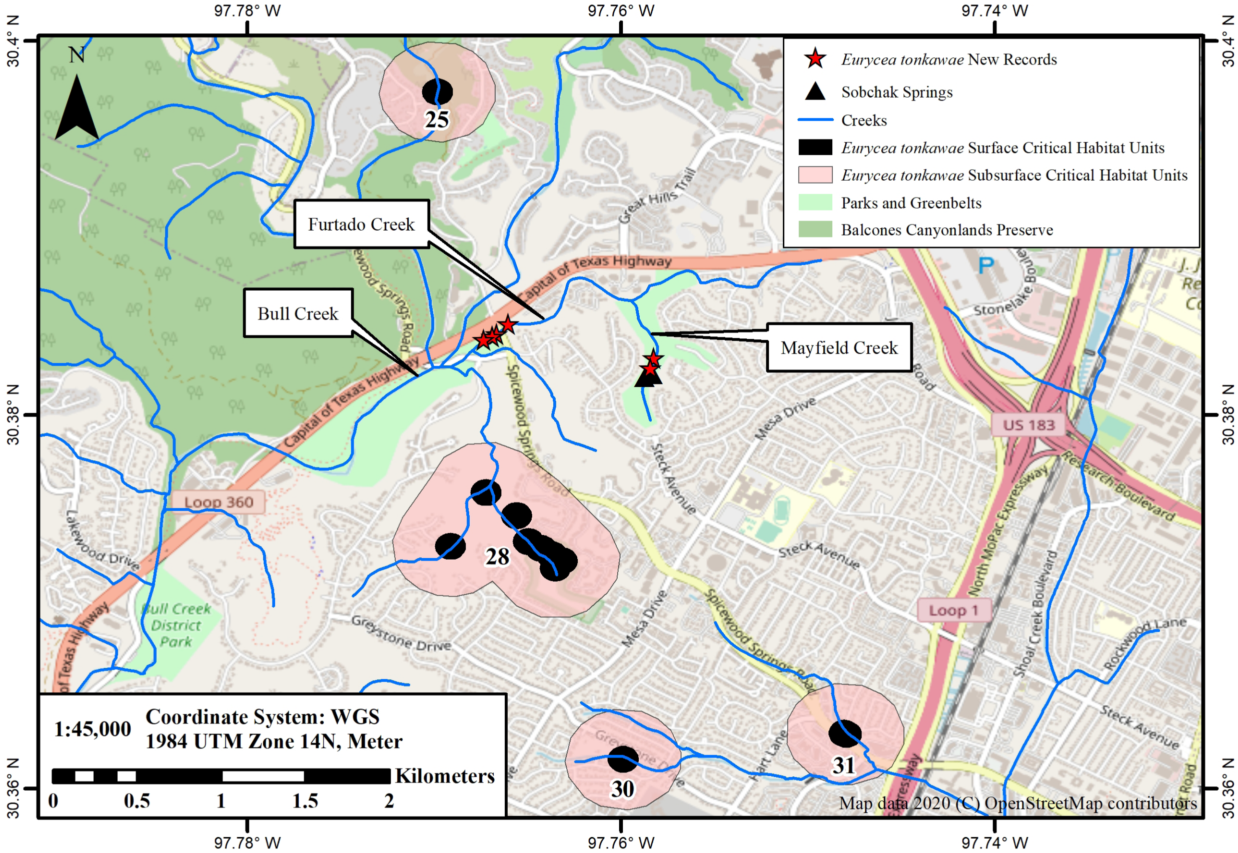

Figure 4. Furtado and Mayfield Creeks, Austin, Texas, USA with new records for *Eurycea tonkawae* and nearby known populations and associated U.S. Fish and Wildlife Service critical habitat units (USFWS 2013b) depicted. Map data 2020 (C) OpenStreetMap contributors.

described by Chippindale et al. (2000). The tail of each salamander had yellow-orange dorsal coloration with irregular boundaries (Fig. 3). The dorsal surface of each salamander's body possessed rows of iridophores, each surrounded by a square shaped light area (Fig. 3). In some cases, the iridophores were surrounded by a light area that is irregular in its shape, and may represent the "rosette" or "starburst" shape described in *E. naufragia*, but it is reportedly not uncommon to see these traits mixed among these two species (Chippindale et al. 2000). The melanophores were most densely clustered along the mid-dorsal area of the body of each salamander (Chippindale et al. 2000). However, we note that morphology does not provide definitive species diagnosis in central Texas *Eurycea* due to general morphological similarity in epigean forms, and considerable within-species variability in troglobitic characters (Sweet 1984; Wiens et al. 2003; Bendik et al. 2013). The most definitive evidence supporting identification as *E. tonkawae* is that the collection localities are geographically embedded among existing known locations for this taxon, which were vetted by multiple phylogenetic analyses (see Chippindale et al. 2000; Krejca et al. 2017; Devitt et al. 2019).

Discussion

Our discovery of *Eurycea tonkawae* within Furtado and Mayfield Creeks is important for the conservation of this taxon because it 1) fills a gap in its geographic distribution, 2) documents occurrence in historically understudied habitat, 3) identifies occupied locations without protection, and 4) demonstrates the potential for discovering new localities. Tributaries occupied by *E. tonkawae* with established federal critical habitat units occur to the northwest and south of Furtado and Mayfield Creeks (Fig. 4). These new locations not only increase the number of known occupied waterbodies but also close a distributional gap among the eastern tributaries to Bull Creek. The nearest previously known location is Barrow Hollow Spring (federal critical habitat unit 28), 900 m south of Furtado Creek and 1.2 km southeast of Mayfield Creek (Fig. 4). Barrow Hollow Spring is included in the same federal critical habitat unit as Stillhouse Hollow, the type locality for *E. tonkawae* (Chippindale et al. 2000).

Most studies on surface populations of central Texas *Eurycea* salamanders have occurred near springs (e.g., Tupa and Davis 1976; Sweet 1982; Bowles et al. 2006; Pierce et al. 2010); only Bendik et al. (2016) systematically searched stream reaches between and downstream of springs. This taxon utilizes various submerged cover objects, such as cobble, leaf litter, and woody debris, as shelter from predators (Davis et al. 2001; Bowles et al. 2006), and substrates with interstitial spaces that provide habitat for prey items, refuge from predators, and access to sub-surface water are considered an essential habitat component (Chippindale 2005). We observed salamanders downstream of the springs both in areas with suitable and sufficient cover objects and substrate, such as cobble and gravel, and in unexpected locations, such as metal culvert corrugations. It is possible that downstream areas in these creeks gain groundwater that we may not be aware of. The process of gaining and losing water within creeks of this region of Texas is not well understood, and we cannot rule out that groundwater enters these systems dynamically with shifting aquifer levels. It is notable that some surveys of Furtado Creek detected no salamanders, and those surveys that detected salamanders required significant effort. For future researchers interested in the occurrence and distribution of this species, we recommend surveying beyond areas immediately adjacent to springs, including anthropogenically modified areas, and warn that substantial survey effort may be necessary to detect salamanders.

The USFWS established critical habitat units around all known, extant *E. tonkawae* populations during the listing process (USFWS 2013b). In addition, a large portion of the known distribution of *E. tonkawae* occurs within the approximate 13,000 hectares of public and private lands that form the Balcones Canyonlands Preserve (BCP) in Travis County, Texas. Although many of the canyons and springs within this region receive a level of protection as participants in the BCP, as well as federal designation as critical habitat, other canyons within this urbanized matrix receive no protection. The sites of our new *E. tonkawae* detections serve as an example of populations of this federally threatened species that exist outside of these protected areas.

The discovery of *E. tonkawae* in these waterbodies additionally demonstrates the potential to identify new populations despite a restricted range in an urban environment. These new localities were undocumented despite occurring in or near a residential development with frequently used hiking trails that border both creeks, and occurring in an area with >20 years of *E. tonkawae* survey history (Davis et al. 2001; Bowles et al. 2006; Bendik et al. 2014; Bendik 2017). A review of aerial imagery within the general Bull Creek area reveals several similar finger tributaries within incised canyons that appear appropriate to investigate for undocumented populations (see Sweet 1982).

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Authors' Contributions

All authors performed fieldwork. ZCA and ARM wrote the manuscript. NFB, RMJ, AL, KS, and KW provided manuscript review and edits.

References

Baker JK (1961) Distribution of and key to the neotenic *Eurycea* of Texas. The Southwestern Naturalist 6 (1): 27–32. https://doi.org/10.2307/3669365

Bendik NF (2017) Demographics, reproduction, growth, and abundance of Jollyville Plateau salamanders (*Eurycea tonkawae*). Ecology and Evolution 7: 5002–5015. https://doi.org/10.1002/ece3.3056

Bendik NF, McEntire KD, Sissel BN (2016) Movement, demographics, and occupancy dynamics of a federally-threatened salamander: evaluating the adequacy of critical habitat. PeerJ 4: e1817. https://doi.org/10.7717/peerj.1817

Bendik NF, Morrison TA, Gluesenkamp AG, Sanders MS, O'Donnell LJ (2013) Computer-assisted photo identification outperforms visible implant elastomers in an endangered salamander, *Eurycea tonkawae*. PLoS ONE 8 (3): e59424. https://doi.org/10.1371/journal.pone.0059424

Bendik NF, Sissel BN, Fields JR, O'Donnell LJ, Sanders MS (2014) Effect of urbanization on abundance of Jollyville Plateau Salamanders (*Eurycea tonkawae*). Herpetological Conservation and Biology 9 (1): 206–222.

Bolger DT, Morrison TA, Vance B, Lee D, Farid H (2012) A computer-assisted system for photographic mark-recapture analysis. Methods in Ecology and Evolution 3: 813–822. https://doi.org/10.1111/j.2041-210x.2012.00212.x

Bowles BD, Sanders MS, Hansen RS (2006) Ecology of the Jollyville Plateau salamander (*Eurycea tonkawae*: Plethodontidae) with an assessment of the potential effects of urbanization. Hydrobiologia 533: 111–120. https://doi.org/10.1007/s10750-005-5440-0

Chippindale PT (2005) *Eurycea tonkawae* Chippindale, Price, Wiens, and Hillis, 2000. In: Lannoo M (Ed) Amphibian declines: the conservation status of United States species. University of California Press, Berkeley, 764–765.

Chippindale PT, Price AH, Wiens JJ, Hillis DM (2000) Phylogenetic relationships and systematic revision of central Texas hemidactyliine plethodontid salamanders. Herpetological Monographs 14: 1–80. https://doi.org/10.2307/1467045

Davis B, Hansen R, McClintock NL, Peacock ED, Turner M, Herrington C, Johns D, Chamberlain DA, Cerda D, Pennington T, Leopold L, Vaughan A, Nuffer D (2001) Jollyville Plateau Salamander water quality and salamander assessment. City of Austin Watershed Protection Department Report, 381 pp. ftp://ftp.austintexas.gov/salamander/JPS%20group/Literature/JPS%20studies/City%20of%20Austin%20-%202001%20-%20Jollyville%20Plateau%20water%20quality%20and%20salamander%20assessment.pdf. Accessed on: 2019-11-8.

Devitt TJ, Wright AM, Cannatella DC, Hillis DM (2019) Species delimitation in endangered groundwater salamanders: implications for aquifer management and biodiversity conservation. Proceedings of the National Academy of Sciences 116 (7): 2624–2633. https://doi.org/10.1073/pnas.1815014116

Gamble T (2014) Collecting and preserving genetic material for herpetological research. Society for the Study of Amphibians and Reptiles, Herpetological Circular No. 41, Salt Lake City, Utah, 50 pp.

Gillette JR, Peterson MG (2001) The benefits of transparency: candling as a simple method for determining sex in red-backed salamanders (*Plethodon cinereus*). Herpetological Review 32 (4): 233–234.

Hillis DM, Chamberlain DA, Wilcox TP, Chippindale PT (2001) A new species of subterranean blind salamander (Plethodontidae: Hemidactyliini: *Eurycea*: *Typhlomolge*) from Austin, Texas, and a systematic revision of central Texas paedomorphic salamanders. Herpetologica 57: 266–280.

IUCN (2019) The IUCN Red List of Threatened Species. Version 2019-2. https://www.iucnredlist.org. Accessed on: 2019-11-8.

Krejca JK, McHenry DJ, McDermid KM, Adcock ZC, Forstner MRJ (2017) Genetic characterization and habitat use of *Eurycea pterophila* salamanders from Jacob's Well, Hays County, Texas. The Southwestern Naturalist 62 (1): 1–13. https://doi.org/10.1894/0038-4909-62.1.1

NatureServe (2019) NatureServe Explorer: An Online Encyclopedia of Life. Version 7.1. NatureServe, Arlington, Virginia. http://explorer.natureserve.org. Accessed on: 2019-11-8.

O'Donnell L, Gluesenkamp A, Herrington C, Schlaepfer M, Turner M, Bendik N (2008) Estimation of Jollyville Plateau Salamander (*Eurycea tonkawae*) populations using surface counts and mark-recapture. City of Austin Watershed Protection Department Report, 110 pp. https://www.fws.gov/southwest/es/Documents/R2ES/LitCited/4TX_Sal/ODonnell_et_al_2008_JPS_Mark_Recapture_Report_Dec08.pdf. Accessed on: 2020-7-21.

O'Donnell L, Turner M, Sanders M, Geismar E, Heilman S, Zebehazy L (2006) Summary of Jollyville Plateau Salamander data (1997 – 2006) and status. City of Austin Watershed Protection Department Report, 50 pp. http://www.austintexas.gov/watershed_protection/publications/document.cfm?id=186291 Accessed on: 2020-7-21.

Pierce BA, Christiansen JL, Ritzer AL, Jones TA (2010) Ecology of Georgetown Salamanders (*Eurycea naufragia*) within the flow of a spring. The Southwestern Naturalist 55 (2): 291–297. https://doi.org/10.1894/WL-30.1

Pierce BA, McEntire KD, Wall AE (2014) Population size, movement, and reproduction of the Georgetown Salamander, *Eurycea naufragia*. Herpetological Conservation and Biology 9: 137–145.

Simmons JE (2015) Herpetological collecting and collections management, 3rd edition. Society for the Study of Amphibians and Reptiles, Herpetological Circular No. 42, Salt Lake City, Utah, 191 pp.

Sweet SS (1982) A distributional analysis of epigean populations of *Eurycea neotenes* in central Texas, with comments on the origin of troglobitic populations. Herpetologica 38 (3): 430–444.

Sweet SS (1984) Secondary contact and hybridization in the Texas cave salamanders *Eurycea neotenes* and *E. tridentifera*. Copeia 1984 (2): 428–441.

Texas Water Science Center (2014) Geologic Database of Texas, 2014-02-01. https://data.tnris.org/collection/79a18636-3419-4e22-92a3-d40c92eced14. Accessed on: 2019-10-29.

Tupa DD, Davis WK (1976) Population dynamics of the San Marcos Salamander, *Eurycea nana* Bishop. The Texas Journal of Science 27 (1): 179–195.

U.S. Fish and Wildlife Service (2013a) Endangered and threatened wildlife and plants; determination of endangered species status for the Austin Blind salamander and threatened species status for the Jollyville Plateau salamander throughout their ranges; final rule. Federal Register 78: 51278–51326. https://www.fws.gov/southwest/es/Documents/R2ES/4TX_Sal_Final_LCH_fL_Rule_Austin_Blind_JPS.pdf. Accessed on: 2019-11-8.

U.S. Fish and Wildlife Service (2013b) Endangered and threatened wildlife and plants; designation of critical habitat for the Austin Blind and Jollyville Plateau salamanders; final rule. Federal Register 78: 51328–51379. https://www.fws.gov/southwest/es/Documents/R2ES/4TX_Sal_Final_LCH_fCH_Rule_Austin_Blind_JPS.pdf. Accessed on: 2019-11-8.

U.S. Fish and Wildlife Service (2014a) Endangered and threatened wildlife and plants; determination of threatened species status for the Georgetown salamander and Salado salamander throughout their ranges; final rule. Federal Register 79: 10235–10293. https://www.fws.gov/southwest/es/Documents/R2ES/4TX_Sal_fL_Georgetown_Salado_FRNotice_2014_03717.pdf. Accessed on: 2019-11-8.

U.S. Fish and Wildlife Service (2014b) United States Fish and Wildlife Service section 10(a)(1)(A) scientific permit requirements for conducting Georgetown, Jollyville Plateau, and Salado Salamander surveys. 18 pp. https://www.fws.gov/guidance/sites/default/files/documents/118_salamander_Survey_protocols.pdf. Accessed on: 2019-11-8.

Wiens JJ, Chippindale PT, Hillis DM (2003) When are phylogenetic analyses misled by convergence? A case study in Texas Cave salamanders. Systematic Biology 52 (4): 501–514. https://doi.org/10.1080/10635150390218222