Zootaxa 5722 (3): 433–442
https://www.mapress.com/zt/

Article

ISSN 1175-5326 (print edition)
ZOOTAXA
ISSN 1175-5334 (online edition)

https://doi.org/10.11646/zootaxa.5722.3.8
http://zoobank.org/urn:lsid:zoobank.org:pub:0FA0744D-45E4-4AC7-8936-AEA5792FBDF1

Cave millipedes of the United States. XVII. A new troglobiotic *Nevadesmus* Shear, 2009 from an Arizona cave (Diplopoda, Polydesmida, Macrosternodesmidae) with observations on associated fauna and ecology

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Abstract

A third species of the macrosternodesmid millipede genus *Nevadesmus* Shear, 2009 is described from a cave in Tonto National Forest, Pinal Co., southern Arizona, USA. This new species, *Nevadesmus superstitiona* Shear, Pape & Marek, **sp. nov.** occurs significantly distant from the localities of the two other species, which occur in Nevada. The epigean and hypogean settings of the cave site and remarks on its natural history are provided. Thirty-two animal taxa are present in the cave, including the new millipede. Four other endemic troglobiotic species are present: a scorpion (*Pseudouroctonus* sp.: Vaejovidae), a terrestrial isopod (*Brackenridgia* sp.: Trichoniscidae), a silverfish (*Speleonycta* sp.: Nicoletiidae) and a thread-legged bug (*Gardena* cf. *elkinsi*: Reduviidae). A resident population of the tailless whip scorpion (*Paraphrynus tokdod*: Amblypygi: Phrynidae) is the first record of this family in an Arizona Cave. Tonto National Forest Cave #34 is the second most species diverse cave currently known in Arizona.

Key words: new species, troglobiont, Pinal County, cave fauna, Cave #34, Tonto National Forest

Introduction

The polydesmidan millipede genus *Nevadesmus* was described by Shear (Shear *et al.* 2009) from caves in White Pine Co., Nevada, USA, and includes the genotype, *Nevadesmus ophimontis* Shear, 2009, and *N. hubbsi* (Chamberlin, 1943). Both of these species show troglobiotic adaptations. Our new species, *N. superstitiona* **sp. nov.,** occurs significantly distant from the localities of the two established species in Nevada. Nevertheless the gonopods and somatic characters clearly indicate that this is a species of *Nevadesmus.*

Millipedes occurring in Arizona caves are poorly known, with only three described species documented prior to the current study: *Colactis utorum* Chamberlin, 1925 (Tynommatidae), *Pratherodesmus ecclesia* Shear, 2009, and *Pratherodesmus voylesi* Shear, 2009 (Macrosternodesmidae) (Shelley 1996; Shear *et al*. 2009; Pape 2016; Shear & Reddell 2017a, 2017b). This seemingly depauperate species richness is unlikely due to a minimal presence of these animals in caves in the state but rather to a lack of search effort. We describe this new species from a cave in the Sonoran Desert in Arizona. With few exceptions the ecology of Arizona caves has received little study, with most of our knowledge resulting from brief inventories of individual caves. Exceptions are longer-term studies at Kartchner Caverns and Arkenstone Cave in southern Arizona, and Bat Cave in Grand Canyon National Park (Welbourn 1999; Muchmore & Pape 1999; Pape 2014, 2016, 2024; Pape & OConnor 2014). We include a preliminary faunal list for the cave supporting the new millipede species. As is typical the majority of species occurring in the cave are arthropods. The epigean and hypogean settings and brief remarks on the biology and ecology of the cave are provided.

Accepted by T. Wesener: 14 Oct. 2025; published: 20 Nov. 2025

Methods

Sampling was accomplished by hand using forceps or a small camelhair brush dipped in ethanol (EtOH). Specimens required for DNA analyses were preserved in 95% EtOH, and others were preserved in 75% EtOH. Field sampling of invertebrates was limited to the minimum number of specimens needed for species identification, description and as vouchers. No pit or other passive trapping devices were used, and therefore preclude bycatch impacts, predation of trapped animals, and potential for spills of toxic fixatives. Ecological notes on the epigean environmental setting and the hypogean cave setting were recorded and are provided for the cave. Cave temperature and humidity were obtained using a Bacharach Instruments sling psychrometer model P/N 0012-7011.

Morphological studies were done using an Olympus SZH stereomicroscope and an Olympus BX50 compound microscope equipped with Nomarski optics. For scanning electron microscopy (SEM), specimens were first cleaned in an ultrasonic cleaner, then mounted on 12.7 mm diameter aluminum stubs using double-sided adhesive carbon discs and allowed to air-dry. These were sputter coated with a 40-nm thick layer of gold and palladium using a Cressington 208HR sputter coater and a Cressington MTM20 thickness controller. SEM micrographs were taken with a FEI Quanta 600 FEG environmental scanning electron microscope. Micrographs were edited and refined using GIMP, and plates were composed in InkScape. An Olympus TG6 F2.0 12.0 megapixel digital camera was used for photographing live animals in the field.

All millipede specimens discussed below are deposited in the Virginia Museum of Natural History, Martinsville, Virginia (VMNH), unless otherwise noted. The remaining arthropod taxa are deposited in the University of Arizona Insect Collection (UAIC) Tucson, Arizona.

The following ecological classifications, modified from Sket (2008), are used in this paper. A troglobiont is an obligate cave animal that cannot live outside of the cave environment. A eutroglophile is a facultative cave animal (population) that is capable of completing its life cycle within caves but may also do so outside caves and in other, similar habitats. A subtroglophile is an animal that has a proclivity for regularly using caves to meet one or more of its ecological needs, such as food, water, shelter and/or reproduction, but must return to the epigean surface environment to meet some required need(s) of its life cycle. A trogloxene is an animal that opportunistically uses cave resources present within its territory. The term incidental (rather than "accidental") is reserved for animals that are attracted to caves, usually due to detection of humidity or odors associated with potential resources, or that randomly enter caves. Animals listed as incidental occurrences, by definition, derive no ecological benefit from their presence in these habitats.

Elliott's biodiversity index (B_1) was calculated for Tonto National Forest Cave #34 [here after TNF Cave #34] (Elliott *et al*. 2017).

Project permission was granted by the Tonto National Forest (2720 permission letter dated March 16, 2023; extended and expanded March 5, 2024; and extended March 24, 2025).

Abbreviations

AMSL	Above mean sea level
SEM	Scanning electron microscopy
TNF	Tonto National Forest
UAIC	University of Arizona Insect Collection
USGS	United States Geological Survey
VMNH	Virginia Museum of Natural History
WRCC	Western Region Climate Center
cx	gonopod coxa
en	endomere
ex	exomere
pf	prefemur of gonopod
s	solenomere

Taxonomy

Order Polydesmida Pocock, 1887

Family Macrosternodesmidae Brölemann, 1916

The family Macrosternodesmidae was based by Brölemann on the genus and species *Macrosternodesmus palicola* Brölemann, 1916, a species that occurs in western Europe mostly as a synanthrope in gardens and disturbed habitats. Shear & Reddell (2017b), in the most recent comprehensive examination of the family, suspected that *M. palicola* may not be a European native, but an immigrant from North America. The gonopods of *M. palicola* are indeed so similar to those of the North American genus *Chaetaspis* Bollman, 1887 that *Macrosternodesmus* could be a junior synonym of *Chaetaspis,* but not of one of the described species of that genus (unpublished SEM study by WAS and PEM). See Lewis (2002) for a review of the genus *Chaetaspis*. The two species of the European genus *Ophiodesmus* Cook, 1896 have also been assigned to Macrosternodesmidae, but have quite different gonopods and may not belong there. One of the *Ophiodesmus* species has been found in Newfoundland, Canada, having been transported there from Europe by humans, and indicating a propensity for these small millipedes to be spread about with some ease (Palmén 1952). Aside from these three species, all remaining macrosternodesmids are endemic to North America. Shear & Reddell (2017b) grouped the American genera into two subfamilies, (1) Macrosternodesminae, including the two European genera and the North American genera *Chaetaspis; Speorthus* Chamberlin, 1952; *Speodesmus* Loomis, 1939; *Tidesmus* Chamberlin, 1943; *Sequoiadesmus* Shear & Shelley, 2008; *Pratherodesmus* Shear, 2009; *Packardesmus* Shear & Shelley, 2019; and *Nevadesmus* Shear*,* 2009; and (2) Nearctodesminae Chamberlin & Hoffman, 1950, with the genera *Nearctodesmus* Silvestri, 1910; *Kepolydesmus* Chamberlin, 1910; *Bistolodesmus* Shelley, 1994; *Ergodesmus* Chamberlin, 1949 and *Leonardesmus* Shelley & Shear, 2006. Shear & Reddell (2017b) were unsure of the position of the genus *Harpogonopus* Loomis, 1960 but a recent SEM study of this genus by WAS and PEM, to be published elsewhere, indicates a close relationship with *Tidesmus* and placement in the Macrosternodesminae. Additional research is necessary to further clarify the internal classification of the family.

Genus *Nevadesmus* Shear, 2019

Two species from Nevada, *N. ophimontis* (the type species) and *N. hubbsi* (Chamberlin, 1943), have been assigned to *Nevadesmus. Nevadesmus hubbsi* is known only from females (Shear & Shelley 2007; Shear *et al.* 2009), and the type locality is near that of *N. ophimontis*, so when males are finally collected, the latter may become a junior synonym of the former. Gonopod structure suggests that *Nevadesmus* is close to *Tidemus*, surface-dwelling species of which are found in the same region of Arizona as the troglobiotic *Nevadesmus superstitiona,* **sp. nov.** (Shear & Shelley 2007).

Nevadesmus superstitiona Shear, Pape & Marek, sp. nov.

Figs. 1–8

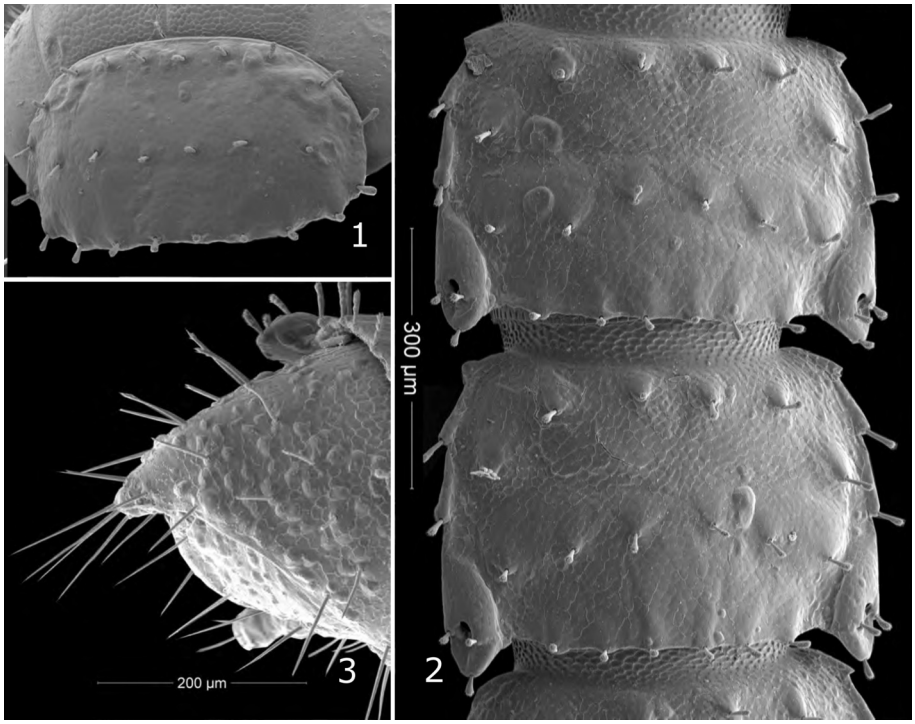
Types. Male holotype (VMNH) and numerous male and female paratypes from Cave #34, Tonto National Forest, Pinal Co., Arizona, collected 28 January and 16 June 2024 by R. B. Pape and C. Poole and 16 June 2024 by R. B. Pape, C. Poole and Sarah Jorgenson. The holotype and paratypes are deposited in VMNH, and additional paratypes are deposited in UAIC.

Etymology. The species epithet, a noun in apposition, refers to the Superstition Mountains, where the cave is located in the southern foothills of the range.

Diagnosis. Distinct from *Nevadesmus ophimontis*, the only other species of the genus for which males are known, in details of the gonopods. In *N. superstitiona,* the solenomere branch bears a long, curved, acute, distal process (**s**, Fig. 6) that is absent in *N. ophimontis.* In *N. ophimontis* the endomere is distally divided into three branches, while *N. superstitiona* the endomere is unbranched except for a small tooth near the tip (**en**, Figs 4, 5).

Description. *Male paratype.* Length, 4.5 mm, width 0.42 mm. Head sparsely setose. Collum (Fig. 1) ovoid, with three rows of clavate setae; the anterior marginal row with 10 setae, the median row with 8, and the posterior

marginal row with 8 setae. Typical midbody poriferous rings (Fig. 2) with very narrow paranota; paranota appearing much as a simple low ridge. Metazonites with three rows of clavate setae originating from low pustules. Clavate setae (Fig. 7) obscurely grooved, with tiny apical and subapical teeth. Anterior row of six setae set slightly back from metazonital margin; lateralmost seta on paranota. A single isolated seta posteriolateral to the row may represent a displaced member of the anterior row, in which case the row actually includes eight setae. Median row slightly curved posteriad, of six setae. Posterior marginal row of six setae. Ozopores opening from prominent calluses, subtended by three clavate setae. Telson (Fig. 3) with long, acute setae. Epiproct short, rounded, with the usual four spinnerets. Paraprocts with three marginal setae. Pregonopodal legpairs markedly crassate.



FIGURES 1–3. *Nevadesmus superstitiona,* **sp. nov. 1**, Collum, dorsal view; **2**. Midbody poriferous rings, dorsal view. **3**. Telson, lateral view.

Gonopods (Figs 4–7) set tightly in socket, coxae closely appressed. Coxae (**cx,** Fig. 4) hemispherical, with groove receiving gonopod telopodites in folded position. Prefemora (**pf**, figs. 4, 5) transverse, lobed, articulating with coxae *via* a long lateral process fitting into a coxal socket. Exomere (**ex**, Figs. 4–6) curved, two-branched, anterior branch broad, blunt, posterior branch gracile, curved, acute. Endomere (**en**, Figs. 4–6) the longest branch, basally broad, curved laterad at nearly a right angle, with small, bifid, subapical tooth. Solenomere (**s**, Fig. 6) roughened with tiny cuticular teeth, bearing long, curved, acute, distal branch that seems to partially lie in a groove in the endomere.

Female paratype. As the male in nonsexual characters, 5.0 mm long, 0.5 mm wide (Fig. 8).

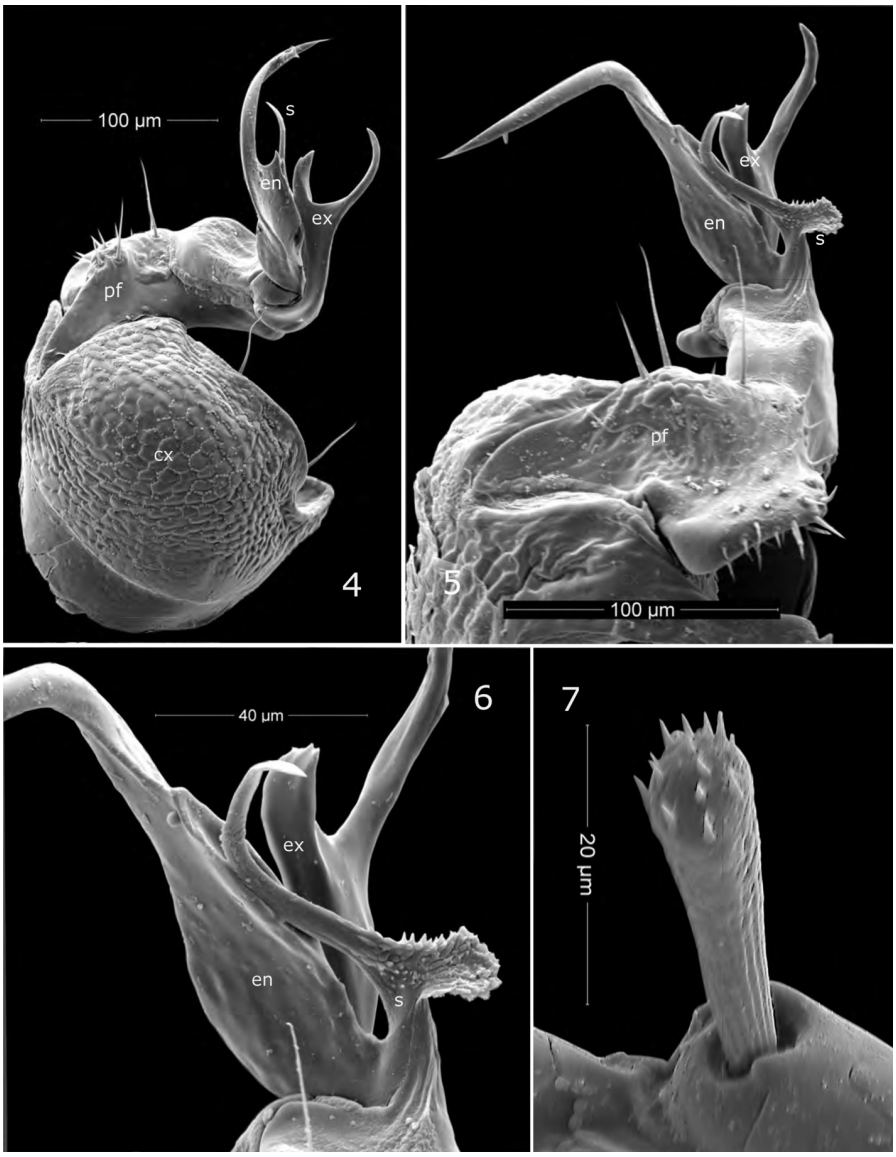
Distribution. Known only from the type locality.

Natural History Remarks about Tonto National Forest Cave #34, Pinal County, Arizona

Setting

The cave is located south of Superior, Arizona and north of the Gila River (Fig. 9) on lands managed by the Tonto National Forest, United States Department of Agriculture. The cave is a complex consisting of several karst features contained within a single small hill, and is situated in steeply dipping (35-55°) Mississippian Age (359–323 mya) Escabrosa Limestone. The complex is developed within a subsidiary fault of the Central Branch of the Concentrator Fault (Richard & Spencer 1998). There are approximately 1,500 meters of humanly traversable passage in the

complex, which are accessible through separate surface connections, and not all of which are connected by human-negotiable passage. The cave temperature is 21° C, and relative humidity varies from 72 to 98% in different areas of the cave.



FIGURES 4–7. *Nevadesmus superstitiona,* **sp. nov. 4**. Right gonopod, lateral view. **5**. Right gonopod, ventral view. **6**. Distal elements of right gonopod, ventral view. **7**. Segmental seta. **Abbreviations**: **cx**, gonopod coxa; **en**, endomere; **ex**, exomere, **pf**, prefemur; **s**, solenomere.

The elevation at the site is approximately 1028 m AMSL. Annual precipitation recorded at the Superior, Arizona meteorological station (028348; 1920-2006) is 46 centimeters (WRCC 2025). The cave occurs near the northern and eastern limits of the Sonoran Desert biome. The habitat at the site is ecotonal between Arizona Upland Subdivision Sonoran Desert and Semidesert Grassland (Turner 1982; Brown & Makings 2014). The saguaro cactus (*Carnegiea gigantea*) is a defining element and keystone species in the Sonoran Desert (Drezner 2014; USGS 2023), but is only sparsely present in the study area. The 180,000 acre Telegraph Fire in 2021, fueled in large part by non-native, invasive red brome grass (*Bromus rubens*), heavily impacted local vegetation. Few saguaros survived this event, and whether they will persist in the area is considered doubtful. Livestock grazing is currently active in the area, and trampling of small saguaros likely inhibits plant recruitment. The presence of fire tolerant non-native invasive grasses has permanently altered the historic plant community and fire regime in the area.

Currently, dominant plant species are mostly forbs and grasses. Common species include flatspine bur ragweed (*Ambrosia acanthacarpa*), desert marigold (*Baileya multiradiata*), brittlebush (*Encelia farinosa*), little

deserttrumpet (*Eriogonum trichopes*), desert globemallow *Sphaeralcia ambigua*), Texas sleepydaisy (*Xanthisma texanum*), purple threeawn (*Aristida purpurea*) and red brome. Significant woody and succulent species are catclaw acacia (*Senegalia greggii*), blue paloverde (*Parkinsonia florida*), crucifixion thorn (*Canotia holacantha*), velvet mesquite (*Neltuma velutina*), Arizona rosewood (*Vauquelinia californica*), skunkbush sumac (*Rhus trilobata*), ocotillo (*Fouquieria splendens*), red barberry (*Mahonia haematocarpa*), banana yucca (*Yucca baccata*), cactus apple (*Opuntia engelmannii*), and saguaro.

FIGURES 8–13. 8. *Nevadesmus superstitiona,* **sp. nov.**, female. **9**. Map showing approximate location of TNF Cave #34. **10**. *Brackenridgia* sp. **11**. *Pseudouroctonus* sp. **12**. *Gardena* cf. *elkinsi.* Fig. **13**. *Paraphrynus tokdod.*

Cave ecology

While all elements of the cave complex are not connected through passages that are navigable by humans, arthropod movement between these areas is considered likely. Thus, the invertebrate biota is suspected to be ecologically connected, and concentrated in areas of suitable habitat within the complex. Studies are ongoing, but to date we have documented 32 animal taxa, predominantly arthropods, integrated into the cave's ecology (Table 1). There is no evidence of current or historic use of the cave by bats. The configuration of the entrance to the main portion of the cave is shaped such that use by bats is likely precluded. Important nutrient input is provided by guano deposited by the resident cave cricket (*Ceuthophilus pinalensis* Hubbell, 1936) population, and scats of the white-throated wood rat (*Neotoma albigula* Hartley, 1894). Other nutrient input is mostly limited to organic materials falling into entrances and meteoric water-borne nutrients transported through the overlying soil horizon and fractured bedrock.

TABLE 1. Animal taxa recorded from Tonto National Forest Cave #34, Pinal County, Arizona.

Order	Family	Species	Association
Rodentia	Muridae	Undet.*	Unknown
	Muridae	*Neotoma albigula*	Trogloxene
Anura	Bufonidae	*Anaxyrus punctatus*	Trogloxene
Urodela	Ambystomatidae	*Ambystoma tigrinum*	Trogloxene
Scorpiones	Vaejovidae	*Pseudouroctonus* sp.	Troglobiont
Amblypygi	Phrynidae	*Paraphrynus tokdod*	Subtroglophile
Araneae	Pholcidae	*Psilochorus* sp.	Eutroglophile
	Nesticidae	*Eidmannella pallida*	Eutroglophile
	Undet. (Agelenidae?)	Undet.	Trogloxene?
	Cybaeidae?	Undet.	Subtroglophile?
	Liocranidae	*Neoanagraphis chamberlini*	Trogloxene
Pseudoscorpiones	Chernetidae	*Allochernes* sp.?	Eutroglophile
Isopoda	Trichoniscidae	*Brackenridgia* sp.	Troglobiont
	Trichoniscidae	*Trichoniscus* sp.?	Eutroglophile?
Polydesmida	Macrosternodesmidae	*Nevadesmus superstitiona* sp. nov.	Troglobiont
Callipodida	Tynommatidae	*Colactis* sp.	Eutroglophile
Lithobiomorpha	Lithobiidae	Undet.	Subtroglophile
Collembola	Entomobryidae?	Undet.	Eutroglophile
Microcoryphia	Machilidae	Undet.	Subtroglophile
Zygentoma	Nicoletiidae	*Speleonycta* sp.	Troglobiont
Orthoptera	Rhaphidophoridae	*Ceuthophilus pinalensis*	Subtroglophile
Blattodea	Corydiidae	*Arenivaga* sp.	Subtroglophile
Hemiptera	Reduviidae	*Gardena* cf. *elkinsi*	Troglobiont
	Pyrrhocoridae	*Dysdercus mimulus*	Incidental
	Rhopalidae	*Liorhyssus hyalinus*	Incidental
Coleoptera	Staphylinidae	Undet. #1	Trogloxene?
	Staphylinidae	Undet. #2	Subtroglophile
	Staphylinidae?	Undet. #3 (larva)	Unknown
	Histeridae	*Haeterius* sp.	Subtroglophile
	Dermestidae	*Anthrenus* sp.? (larva)	Trogloxene
	Anobiidae	*Niptus ventriculus*	Subtroglophile
	Tenebrionidae	*Eleodes c. carbonaria*	Trogloxene
	Tenebrionidae?	Undet. (larva)	Unknown
Hymenoptera	Braconidae	Undet.	Unknown
	Formicidae	*Neivamyrmex nigrescens*	Subtroglophile
	Formicidae	*Nylanderia terricola*	Subtroglophile
Diptera	Mycetophilidae	Subf. Keroplatinae? (larva)	Subtroglophile
	Sphaeroceridae	*Spelobia* sp.?	Subtroglophile?
	Tachinidae?	Calyptrate muscoid pupa	Potential parasite**

*Mouse skeleton embedded in calcite flowstone on floor breakdown.

**Potential internal parasite of *Ceuthophilus pinalensis*.

The top invertebrate predator in the cave is the tailless whip scorpion *Paraphrynus tokdod*, Cazzaniga & Prendini, 2024 (Amblypygi: Phrynidae; (Fig. 13). Amblypygids are primarily a tropical group, and were previously recorded from caves in the United States only from the Edwards Plateau in central Texas. This is the first cave record of an amblypygid in Arizona. The population is considered subtroglophilous. The other large predator is an undescribed scorpion (Vaejovidae: *Pseudouroctonus* sp.; Fig. 11). Five of the arthropod taxa found in the cave are considered endemic troglobiotic species, including *N. superstitiona* (Fig. 8), the *Pseudouroctonus* sp. scorpion (Fig. 11), a terrestrial isopod (Trichoniscidae: *Brackenridgia* sp.?; Fig. 10), a nicoletiid silverfish (Nicoletiidae: *Speleonycta* sp.), and an undescribed thread-legged bug (Reduviidae: *Gardena* cf. *elkinsi*); Fig. 12.

The diverse and exceptional fauna found in the cave make it the second most diverse cave currently known in Arizona after Kartchner Caverns in Kartchner Caverns State Park, near Benson, Arizona. Elliott's biodiversity score (B_1) for TNF Cave #34 is 608. The B_1 score for Kartchner Caverns is 4408 (Pape, unpublished data).

Acknowledgments

We thank Clint Poole, who brought our attention to the rich cave fauna present in TNF Cave #34, and who provided field logistical support for this effort. Clint Poole, Shelley Littin, Joel Norby, Sarah Jorgenson and Beth Santoro assisted with invertebrate searches in the cave. The thread-legged bug photograph (Fig. 12) is by C. Poole. We thank Adam Bromley, District Ranger and Grace Bombulum, Geologist of the Globe, Arizona Ranger District for permission to study and sample in caves on the Tonto National Forest. This work was supported by a National Science Foundation grant to P. Marek (Division of Environmental Biology # 2433355). Steve McCartney in the Nanoscale Characterization and Fabrication Laboratory at Virginia Tech assisted with scanning electron microscopy. We thank Esty Pape for proofreading the manuscript.

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