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# CAVE BIODIVERSITY OF CUMBERLAND GAP NATIONAL HISTORICAL PARK

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Abstract

Recognized as an important pathway between the east coast and the interior of the United States, much of the Cumberland Gap has been protected as part of the Cumberland Gap National Historical Park (CUGA). CUGA also contains extensive karst habitats, including Gap Cave, one of the longest caves in Virginia. With the aim of better understanding the cave biodiversity of CUGA, we conducted biological surveys in park caves and compiled records of other animals from CUGA caves, including bat monitoring data extending back more than 35 years. Results of that work include: (1) collecting five new cave-obligate species (troglobionts) from CUGA caves, increasing the number of troglobionts known from CUGA from 11 to 16; (2) increasing the total records of troglobionts in CUGA caves from 17 to 39; (3) finding an undescribed isopod (now described as *Lirceus zigleri*) in the Gap Cave stream; (4) noting six species of bats, including two federally endangered species—Indiana bats (*Myotis sodalis*) and northern long-eared bats (*Myotis septentrionalis*)—from CUGA caves; and (5) recognizing that Gap Cave once hosted one of the largest known populations of Indiana bats in Virginia. We present an annotated list of the animals found in the caves of the park. The caves of the Cumberland Gap National Historical Park provide critical habitat to two groups of species with distinct conservation concerns: poorly known troglobionts that exhibit extreme endemicity and bats under threat from white-nose syndrome disease.

## INTRODUCTION

Situated at the junction of Kentucky, Virginia, and Tennessee, the approximately 8,000-hectare Cumberland Gap National Historical Park (CUGA) commemorates and preserves the historic path between the east coast and the interior of the continent. Less well known are the biologically significant karst habitats found throughout the park. The most famous of these is Gap Cave, which was first operated as a show cave in 1888 (Matthews, 2008) and is still open for guided visits today. At more than 30 kilometers in length, it is one of the longest caves in Virginia. CUGA contains more than two dozen other caves, most of which are closed to the public. Most of the caves in CUGA are developed in the Mississippian-aged Greenbrier (Newman) Limestone that crops out along the southern slope of Cumberland Mountain. Caves east of Cumberland Gap drain to the west through Gap Cave to a spring below the downstream (Cudjos) entrance. Some of these caves have been mapped by the Cave Research Foundation. However, we have an incomplete picture of the biodiversity of CUGA caves.

The Cumberland Gap National Historical Park spreads across four counties—Claiborne County in Tennessee, Lee County in Virginia, and Bell and Harlan Counties in Kentucky (Fig. 1). Prior to this study, 11 cave-obligate species (troglobionts) had been reported from caves within CUGA. Forty-five additional troglobionts are known from the four-county region surrounding CUGA (Table 1; Niemiller and Zigler, 2013; Holsinger et al., 2013; Christman et al., 2016). Most of the troglobiont records are from Lee County, a hotspot for cave biodiversity, exhibiting extraordinary levels of cave-obligate biodiversity and single-county endemic troglobionts (Culver et al., 2000; Shear, 2011; Holsinger et al., 2013). Troglobionts often have highly restricted ranges and may be endemic to one cave or to a handful of nearby caves (Christman et al., 2005). As a result of such extreme endemism, cave communities typically include many species of conservation concern (Culver et al., 2000; Niemiller et al., 2018). Of the troglobionts known from CUGA, three are endemic to the park and another is known from only one additional site outside the park.

Caves also provide habitat for bats, particularly as sites for hibernation. In recent years, bat populations in the Appalachians have been affected by *Pseudogymnoascus destructans*, the causative agent of the white-nose syndrome dis-

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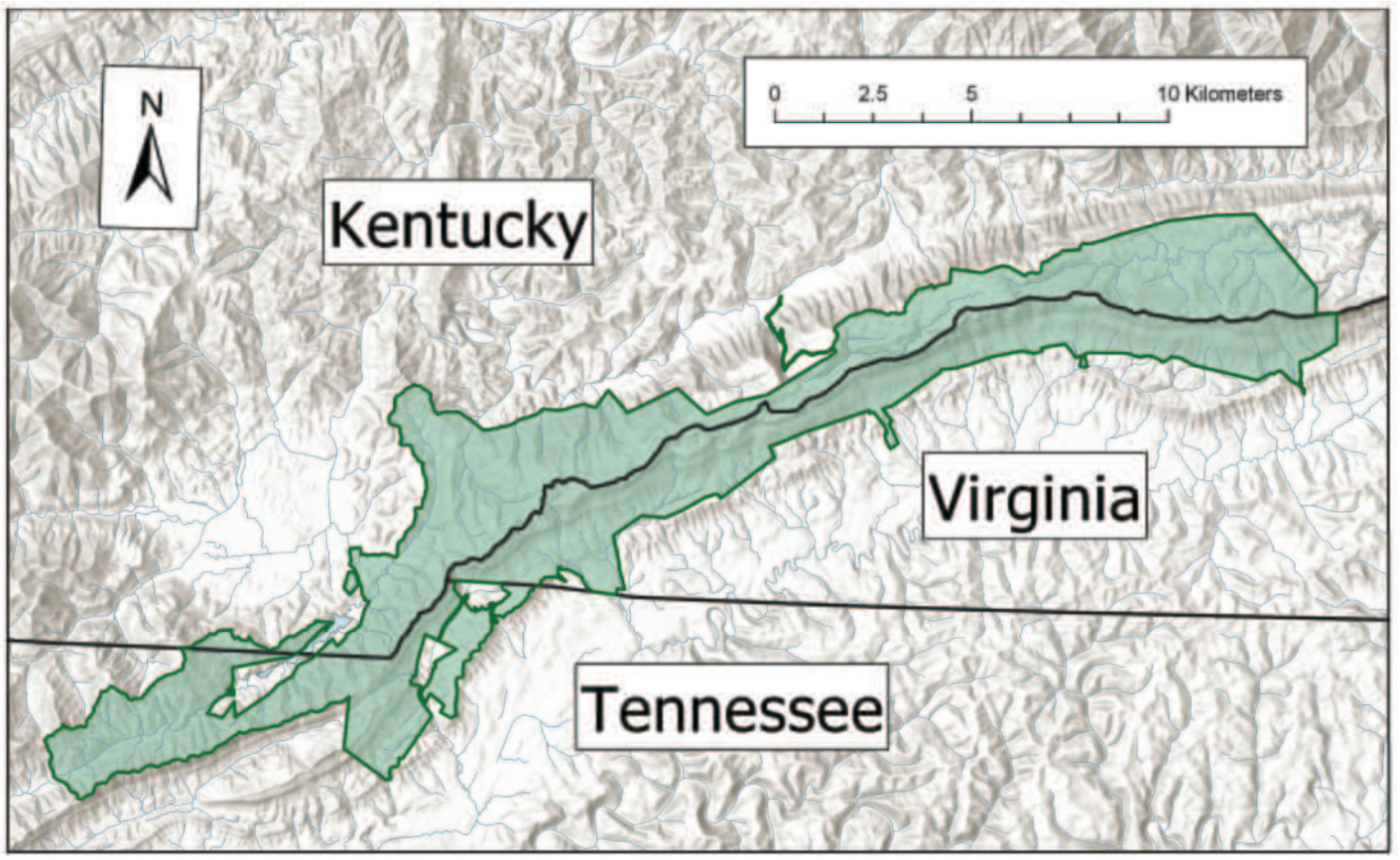


Figure 1. The Cumberland Gap National Historical Park lies at the junction of Kentucky, Virginia, and Tennessee. State boundaries are indicated by black lines, and the extent of the park is green.

**Table 1. Summary of troglobiont records for counties around the Cumberland Gap National Historical Park.**

| County | State | Caves with Troglobiont Records | Records | Troglobionts |
|---|---|---|---|---|
| Claiborne | Tennessee | 16 | 45 | 16 |
| Lee | Virginia | 78 | 254 | 49 |
| Bell | Kentucky | 1 | 4 | 4 |
| Harlan | Kentucky | 1 | 4 | 4 |
| Total | | 96 | 307 | 56[a] |

[a] Some troglobionts are known from more than one of these counties. As a result, this number is not the sum of the values above.

ease (WNS). *Pseudogymnoascus destructans* is a psychrophilic (cold loving) fungus first detected in bats in New York in winter 2006–2007 (Blehert et al., 2009). The fungus invades the exposed skin of bats causing cutaneous lesions, increasing the number of arousal bouts during hibernation, and depleting fat reserves needed to survive the winter. The disease also disrupts the physiology of bats affecting water balance and causing dehydration (Cryan et al., 2010). WNS was first detected in Virginia in the winter of 2009 at sites in the central and northern mountain regions and in CUGA in January 2013. By 2013 little brown bats (*Myotis lucifugus*) had declined statewide by 99.0 %, tri-colored bats (*Perimyotis subflavus*) by 89.5 %, and Indiana bats (*Myotis sodalis*) by 33.5 % compared to pre-WNS count averages in Virginia (Powers et al., 2015). By 2018 little brown bats had declined by 99.1 %, tri-colored bats by 94.1 %, and Indiana bats by 36.1 % compared to pre-WNS count averages (Cheng et al., 2021). While a decline of 36.1 % in Indiana bats does not appear as dramatic as the 90+ % decline for little brown and tri-colored bats, the comparisons are with pre-WNS count averages. Indiana bats were already declining in Virginia before WNS, and when compared to the highest historic count as opposed to the average count, the overall decline is 82.8 %.

To characterize the cave biodiversity of CUGA more fully, we conducted bioinventories of CUGA caves and integrated our observations with all previously available information about CUGA cave biodiversity.

## METHODS

We conducted bioinventories in 10 caves of CUGA during 2019. When available, we relied on cave maps shared by the Virginia Speleological Survey, most of which were developed by the Cave Research Foundation, to ensure we visited all accessible parts of the caves. The bioinventories primarily consisted of visual encounter surveys (as described in Zigler et al., 2020). We collected vouchers of invertebrate specimens, and made note of, but did not collect, vertebrate specimens. In several cases, we placed baits (canned tuna) in caves for 48 hours, after which we returned to collect specimens attracted to the bait. Specimens were preserved in 100 % ethanol in the field, and later sorted and stored in ethanol at −20 °C or −80 °C prior to identification. Specimens were identified by morphology.

Survey counts of hibernating bats are conducted every other year in accordance with U.S. Fish and Wildlife Service's (USFWS) Indiana Bat Hibernacula Survey Guidelines (Hicks et al., 2009), typically from January to early March. Historically these counts were conducted during odd numbered years before SARS-CoV-2 became prevalent in the United States. Because of concerns over potential human transmission of SARS-CoV-2 to bats, the USFWS and State Wildlife Resource Agencies agreed to postpone the 2021 count to 2022 and resume biennial counts during even numbered years. Cave bats typically utilize caves during the winter months (November through March) where they hibernate during periods of low to no insect activity, their primary food source. Hibernating cave bats have fidelity not only to specific caves, but often to specific passages in caves, allowing the monitoring of population trends through visual and photographic counts. For comparative purposes, hibernacula counts are typically standardized by counting the same cave passages biennially. Records presented here before 1995 did not document passages surveyed but are believed to be the same passages surveyed post-1995.

We compiled additional records of animals in CUGA caves from the literature (especially Holsinger and Culver, 1988; Holsinger et al., 2013; and Christman et al., 2016), from CUGA databases (J. Beeler, pers. comm.), and from other sources (K. Helf, pers. comm.). We combined our new records with all available earlier records into a single list. The list also includes records from a handful of caves near CUGA in Claiborne County, Tenn. (Powell Mountain Cave, Obie Mill Cave, Station Creek Cave, and Tom Balls Cave) for which we had additional information.

### Cave Names

Gap Cave has previously been called Cudjos (or Cudjo's) Cave, King Solomons (or Solomon's) Cave, Cumberland Gap Cave, and John A. Murrell Cave (Matthews, 2008). In this report, we refer to it as Gap Cave. Big Salt Cave (also called Cumberland Gap Saltpetre Cave or Saltpeter Cave) was connected to Gap Cave in 1983 (Matthews, 2008) and the two caves are now recognized as a single cave system. Some older records are from Big Salt Cave and we report them that way while recognizing that is part of the Gap Cave System. At times (particularly for bat records) we distinguish between the Big Salt Section (upstream) and the Cudjos Section (downstream) of Gap Cave. To aid in protecting listed bats, alternate names (e.g., Cave A, Cave B) were used for ungated caves in conjunction with information about bat use. Actual names for these caves may be requested from resource managers at CUGA.

## RESULTS

The combined cave records list has 730 entries (Appendix 1). The majority of the records are of invertebrates (62 %, 449/730) with fewer vertebrate (38 %, 281/730) observations. Three invertebrate phyla are represented: Annelida (6 records), Arthropoda (423 records), and Mollusca (18 records). In the course of this project, we increased the number of troglobiont records from CUGA from 17 to 39 and the number of known troglobionts from 11 to 16. Bat monitoring records reaching as far back as 1977 revealed six bat species present across nine caves in CUGA. We provide an annotated list of animals from CUGA caves below. A summary of the Federal status (if any) and NatureServe conservation status rankings (from explorer.natureserve.org) for all troglobionts and for select mammals (including all bats) is presented in Table 2.

## ANNOTATED LIST OF TROGLOBIONTS FROM CUGA

### Arachnida

*Hesperochernes mirabilis* (Banks, 1895) – Southeastern Cave Pseudoscorpion
Sites known from CUGA: Pack Rat Cave (new record)

Commonly associated with bat guano and rodent nests, this pseudoscorpion is one of the most widespread troglobionts in eastern North America (Christman and Culver, 2001). This is the first observation of *H. mirabilis* in CUGA.

**Table 2. Federal Status (Endangered (EN), Proposed Endangered (PE), or Under Review (UR)) and NatureServe Global and State (for Virginia, Tennessee, and Kentucky) Conservation Status rankings for all troglobionts and select mammals known from caves of the Cumberland Gap National Historical Park.**

| Taxon and Species | Common Name | Federal Status | NatureServe Rankings | | | |
|---|---|---|---|---|---|---|
| | | | Global | Va. | Tenn. | Ky. |
| Trogliobionts | | | | | | |
| Arachnida | | | | | | |
| *Hesperochernes mirabilis* | Southeastern Cave Pseudoscorpion | | G5 | SNR | S3 | S3 |
| *Kleptochthonius lutzi* | Lutz's Cave Pseudoscorpion | | G1 | S1 | | |
| *Lissocreagris valentinei* | Valentine's Cave Pseudoscorpion | | G1 | S1 | | |
| *Phanetta subterranea* | Subterranean Sheetweb Spider | | G5 | S4 | S4 | S4 |
| Crustacea | | | | | | |
| *Bactrurus angulus* | Cumberland Gap Cave Amphipod | | G1 | S1 | S1 | |
| *Crangonyx antennatus* | Appalachian Valley Crangonyctid | | G5 | S3 | S4 | |
| *Stygobromus cumberlandus* | Cumberland Cave Amphipod | | G3 | S1S2 | | |
| *Caecidotea cumberlandensis* | Cumberland Gap Cave Isopod | | G1 | S1 | | |
| *Lirceus zigleri* | Zigler's Cave Isopod | | | | | |
| Hexapoda | | | | | | |
| *Litocampa* sp. | A cave dipluran | | | | | |
| *Pogonognathellus danieli* | A cave springtail | | | | | |
| *Pseudosinella hirsuta* | A cave springtail | | G5 | S1 | S3 | S4 |
| *Pseudanophthalmus hirsutus* | Cumberland Gap Cave Beetle | | G1 | S1 | S1 | |
| *Spelobia tenebrarum* | Cave Dung Fly | | G5 | S1 | S4S5 | S3 |
| Myriapoda | | | | | | |
| *Pseudotremia nodosa* | A cave millipede | | G4 | S4 | S2S3 | |
| *Pseudotremia valga* | A cave millipede | | G1 | S1S2 | S1? | |
| Mammalia | | | | | | |
| Chiroptera | | | | | | |
| *Eptesicus fuscus* | Big Brown Bat | | G5 | S5 | S5 | S5 |
| *Myotis leibii* | Eastern Small-footed Myotis | | G4 | S2 | S2 | S2 |
| *Myotis lucifugus* | Little Brown Bat | UR | G3 | S2 | S3 | S2 |
| *Myotis septentrionalis* | Northern Long-eared Bat | EN | G2 | S2 | S1 | S1 |
| *Myotis sodalis* | Indiana Bat | EN | G2 | S1 | S1 | S1 |
| *Perimyotis subflavus* | Tri-colored Bat | PE | G3 | S2 | S2 | S2 |
| Rodentia | | | | | | |
| *Neotoma magister* | Allegheny Woodrat | | G3 | S3 | S3 | S3 |

*Kleptochthonius lutzi* (Malcolm and Chamberlin, 1961) – Lutz's Cave Pseudoscorpion
Sites known from CUGA: Gap Cave

This pseudoscorpion is known only from Gap Cave. Immature *Kleptochthonius* were collected from Skylight Cave in 1971 by W. A. Shear. Those specimens plus additional *Kleptochthonius* collected from Cliff Cave (a female) and Grassy Springs Cave (a nymph) during this study may correspond to *K. lutzi*.

*Lissocreagris valentinei* (Chamberlin, 1962) – Valentine's Cave Pseudoscorpion
Sites known from CUGA: Gap Cave

This pseudoscorpion is known only from Gap Cave. W. B. Muchmore identified a specimen from Indian Cave to *Lissocreagris* that is listed as *L. valentinei* in Holsinger et al. (2013) and this unconfirmed record may represent a range expansion from the only known locality.

*Phanetta subterranea* (Emerton, 1875) – Subterranean Sheetweb Spider
Sites known from CUGA: Big Salt Cave, Cliff Cave (new record), Gap Cave, Grassy Springs Cave (new record), Salamander Cave (new record), Tiprell Spider Cave (new record)

This spider may be the most widespread troglobiont in eastern North America (Christman and Culver, 2001).

**Crustacea**

*Bactrurus angulus (*Koenemann and Holsinger, 2001) – Cumberland Gap Cave Amphipod
Sites known from CUGA: Big Salt Cave

This amphipod is also known from two sites in Claiborne County, Tenn. (Koenemann and Holsinger, 2001).

*Crangonyx antennatus* (Cope and Packard, 1881) – Appalachian Valley Crangonyctid
Sites known from CUGA: Big Salt Cave, Gap Cave

This widespread amphipod is known from caves of the Valley and Ridge from southwest Virginia through eastern Tennessee to northeast Alabama and northwest Georgia (Zhang and Holsinger, 2003).

*Stygobromus cumberlandus* (Holsinger, 1978) – Cumberland Cave Amphipod
Sites known from CUGA: Cliff Cave, Indian Cave

This amphipod is known from seven caves and a well in Lee County, Scott County, and Wise County, Va. (Holsinger et al., 2013).

*Caecidotea cumberlandensis* (Lewis, 2000) – Cumberland Gap Cave Isopod
Sites known from CUGA: Cliff Cave, Indian Cave

This species is completely eyeless and unpigmented, which, like all taxa assigned to the *Stygia* species group, is an obligate inhabitant of subterranean waters (Lewis, 2000). *Caecidotea cumberlandensis* is morphologically similar and most closely genetically related to *C. bicrenata* populations in southcentral Kentucky (Lewis, et al., in press). Described from specimens in two caves located high on Cumberland Mountain in CUGA (Lewis, 2000), the species has recently been discovered in another cave on Cumberland Mountain in Lee County, Va. (Lewis, et al., in press).

*Lirceus zigleri* – Zigler's Cave Isopod
Sites known from CUGA: Gap Cave (new record)

This previously unknown isopod was collected from the underside of rocks in the Gap Cave stream, upstream of the public tour route. This unpigmented, vestigially eyed species known only to the Gap Cave was described by Lewis, et al. (2023). Molecular genetic analysis suggests that its closest relative is another undescribed species, which is fully pigmented and eyed, inhabiting another Lee County cave and spring system about 5 km to the east. These species in turn are part of an assemblage of morphologically and genetically closely related cryptic species of *Lirceus* that occur in the Appalachian Valley. Over half a dozen stygobiontic *Lirceus* are now known, the majority of which occur in southwestern Virginia (Lewis et al., 2023).

**Hexapoda**

*Litocampa sp.* – A cave dipluran
Sites known from CUGA: Gap Cave, Olde Formation Pit

Cave diplurans (likely *Litocampa*) have been reported from Gap Cave and Olde Formation Pit. We collected a dead and partially decayed individual from Gap Cave. *Litocampa cookei* is a widespread species that has been reported from sites in Lee County, Va. and Claiborne County, Tenn., but there are numerous undescribed species in this genus (Holsinger et al., 2013), so it is unclear what species is/are present in CUGA.

*Pogonognathellus danieli* (Felderhoff, Bernard, and Moulton, 2010) – A cave springtail
Sites known from CUGA: Grassy Springs Cave (new record), Pack Rat Cave (new record), Salamander Cave (new record)

This species was described by Felderhoff et al. (2010) from specimens collected from a cave in the Great Smoky Mountains National Park (Blount County, Tenn.). These are the first records of this species from Virginia.

*Pseudosinella hirsuta* (Delamare Deboutteville, 1949) – A cave springtail
Sites known from CUGA: Cliff Cave, Gap Cave, Grassy Springs Cave (new record), Indian Cave (new record), Pack Rat Cave (new record), Skylight Cave

A widespread cave springtail (Christman and Culver, 2001).

*Pseudanophthalmus hirsutus* (Valentine, 1931) – Cumberland Gap Cave Beetle
Sites known from CUGA: Big Salt Cave, Cliff Cave (new record), Gap Cave, Grassy Springs Cave (new record), Indian Cave

The only other known site for this beetle is Powell Mountain Cave in Claiborne County, Tenn. There are additional visual records of *Pseudanophthalmus* from Olde Formation Pit and Pack Rat Cave of CUGA (S. Thomas and K. Helf, pers. comm.); these likely represent *P. hirsutus* as well.

*Spelobia tenebrarum* (Aldrich, 1897) – Cave Dung Fly
Sites known from CUGA: Cliff Cave (new record), Pack Rat Cave (new record), Skylight Cave (new record)

Though common on scat in caves of the southern Appalachians (Marshall and Peck, 1984; Christman and Culver, 2001), this dung fly is only rarely recorded from Virginia caves (Holsinger et al., 2013). These are the first observations of *S. tenebrarum* in CUGA.

**Myriapoda**

*Pseudotremia nodosa* (Loomis, 1939) – A cave millipede
Sites known from CUGA: Salamander Cave (new record)

This millipede is known from two dozen caves in Lee County, Va. and another dozen caves in Claiborne County, Union County, and Hancock County, Tenn. (Shear, 2011; Holsinger et al., 2013; Christman et al., 2016). This is the first observation of *P. nodosa* in CUGA.

*Pseudotremia valga* (Loomis, 1943) – A cave millipede
Sites known from CUGA: Big Salt Cave, Cliff Cave (new record), Gap Cave, Indian Cave (new record), Skylight Cave (new record)

This millipede was first collected from Gap Cave in 1924. Including these new records, *P. valga* is now known from seven caves in Lee County, Va. and Claiborne County, Tenn. (Shear, 2011; Holsinger et al., 2013). Based on pigmentation and eye structure, Shear (2011) considered it a troglophile, but it has only been reported from caves and Holsinger et al. (2013) considered it a troglobiont.

## ADDITIONAL SPECIES KNOWN FROM CUGA CAVES

**Arachnida**

*Calymmaria persica* (Hentz, 1847) – Cave Funnel-web Spider

This spider is common in CUGA caves.

*Meta ovalis* (Gertsch, 1933) – Eastern Cave Long-jawed Spider

This orb weaver is nearly ubiquitous in CUGA caves.

*Nesticus carteri* (Emerton, 1875) – Carter's Cave Spider

This spider is common in CUGA caves. It was previously reported from Gap Cave and Skylight Cave (Gertsch, 1984). In addition to those sites, we collected specimens from Indian Cave, Little Saltpeter Cave, Pack Rat Cave, and Salamander Cave.

*Pholcus jusahi* (Huber, 2011) – Jusahi's Cellar Spider

Described from Jackson County, NC (Huber, 2011), our collection from Skylight Cave is the first record of this species from Virginia.

**Hexapoda**

*Euhadenoecus fragilis* (Hubbell and Norton, 1978) – A cave cricket

This cricket is ubiquitous and common in caves of CUGA. Its range extends north to the Greenbrier Valley in West Virginia, and south to Claiborne County, Tenn. (Hubbell and Norton, 1978).

*Oecothea specus* (Aldrich, 1897) and *Amoebaleria sp.* – Red-eyed flies

These are the common red-eyed (heleomyzid) flies found in caves of the southern Appalachians, including CUGA. *Amoebaleria* flies are larger than *Oecothea* individuals. Work in the Ozarks identified two species of *Amoebaleria* in caves there (Barnes et al., 2009).

*Spelobia semioculata* (Richards, 1965) and *S. clunipes* (Meigen, 1830) – Dung flies

CUGA caves support several species of dung flies in the genus *Spelobia*. In addition to *S. tenebrarum* (a troglobiont, described above), we also collected *S. semioculata* in Salamander Cave and *S. clunipes* in Little Saltpeter Cave.

**Mammalia - Chiroptera**

*Eptesicus fuscus* (Beauvois, 1796) – Big Brown Bat
Sites known from CUGA: Gap Cave System (Big Salt and Cudjos Sections), Little Saltpeter Cave, Cave A, Cave C, Cave E

While big brown bats are rarely observed hibernating in large clusters, they can be found in many caves but not consistently from year to year. The Big Salt Section of Gap Cave has the most consistent records for big brown bats, although in low numbers (Table 3). While big brown bats can contract WNS, their populations do not appear to be significantly impacted.

*Myotis leibii* (Audubon and Bachman, 1842) – Eastern Small-footed Myotis
Sites known from CUGA: Gap Cave System (Big Salt Section), Little Saltpeter Cave, Cave C, Cave D

Like the big brown bat, hibernacula records for the eastern small-footed myotis are variable from year to year. The fluctuations in counts are typical of this species throughout hibernacula in Virginia. The eastern small-footed myotis roosts in caves, mines, rocky shelters, talus slopes, and other rock features where finding individuals can be difficult, thus contributing to variations in counts. The Big Salt Section of Gap Cave has the most consistent records for the presence of small-footed bats with a single record from Cave C, Little Saltpeter, and Cave D caves (Table 4). Despite fatalities caused by WNS, small-footed myotis populations appear stable in Virginia.

**Table 3. Hibernacula counts for Big Brown Bats (*Eptesicus fuscus*) by year and site in Cumberland Gap National Historical Park.**

| Year | Gap Cave – Big Salt Section | Gap Cave – Cudjos Section | Cave C | Little Saltpeter Cave |
|---|---|---|---|---|
| 1987 | 11 | | 0 | |
| 2001 | 0 | | 0 | |
| 2003 | 1 | | 0 | |
| 2005 | 0 | | 0 | |
| 2007 | 0 | | 0 | |
| 2009 | 2 | | 0 | |
| 2011 | 4 | | 1 | |
| 2013 | 4 | | 0 | 1 |
| 2015 | 5 | 0 | 0 | 0 |
| 2017 | 7 | 0 | 0 | 0 |
| 2019 | 1 | 3 | 0 | 1 |
| 2022 | 9 | 4 | 0 | 1 |

**Table 4. Hibernacula counts for Eastern Small-footed Myotis (*Myotis leibii*) by year and site in Cumberland Gap National Historical Park.**

| Year | Gap Cave – Big Salt Section | Cave C | Little Saltpeter Cave | Cave D |
|---|---|---|---|---|
| 1987 | 1 | 0 | | |
| 2001 | 0 | 0 | | |
| 2003 | 0 | 0 | | |
| 2005 | 2 | 0 | | |
| 2007 | 2 | 0 | | |
| 2009 | 0 | 1 | | |
| 2011 | 5 | 0 | | |
| 2013 | 2 | 0 | 0 | 0 |
| 2015 | 1 | 0 | 0 | 0 |
| 2017 | 6 | 0 | 0 | 0 |
| 2019 | 4 | 0 | 0 | 2 |
| 2022 | 13 | 0 | 2 | 0 |

*Myotis lucifugus* (LeConte, 1831) – Little brown Bat
Sites known from CUGA: Gap Cave System (Big Salt and Cudjos Sections), Indian Cave, Lewis Hollow Bridge Cave, Cave A, Cave C, Cave D, Cave E

This was the most abundant species observed in hibernacula throughout the mountain regions of Virginia before the onset of WNS. From 2009 through 2022, little brown bat populations declined by >99 % in Virginia (Powers et al., 2015; Cheng et al., 2021). In the Big Salt Section of Gap Cave and Cave C, little brown bats represented 40.2 % and 68.3 % of the hibernating bats counted pre-WNS, respectively. In 2022, little brown bats represented 5.4 % and 5.3 % of the hibernating bats, respectively. While little brown bat counts fluctuated during pre-WNS years, there was a marked increase in numbers in the Big Salt Section of Gap Cave and at Cave C starting in 2011, two years after WNS was first documented in Virginia. This type of increase was documented at other WNS-infected sites where individuals would congregate at the entrances of caves apparently waiting to forage at dusk. These increased numbers may represent individuals that were not counted historically due to the limited areas surveyed in caves or may represent immigration of individuals from other WNS-impacted caves looking for alternative roosting sites. The Cudjos Section in Gap Cave had a high count of 655 little brown bats in 2009. Surveys in the Cudjos Section were not conducted in 2011 and 2013 to accommodate a separate WNS project studying behavioral changes in hibernating bats pre- and post-WNS. Surveys resumed in 2015 with a marked decline from 2009 followed by an increasing trend through 2022 (Figure 2). While little brown bat populations appear to be stabilizing in many hibernacula in Virginia, the Cudjos hibernaculum is one of the few showing an expanding population. This may represent an actual increase in little brown bats in CUGA through fecundity or a behavioral response of individuals migrating from surrounding caves.

*Myotis septentrionalis* (Merriam, 1895) – Northern Long-eared Bat
Sites know from CUGA: Gap Cave System (Big Salt and Cudjos Sections), Indian Cave, Lewis Hollow Bridge Cave, Little Saltpeter Cave, Cave D, Cave E

The northern long-eared bat is a very difficult bat to survey at hibernacula due to their behavior of roosting in deep crevices and under rocks (Whitaker 1982; Caceres and Barclay, 2000). For that reason, hibernacula surveys are not a reliable technique to assess trends or presence-absence for this species, at least in Virginia. The highest hibernaculum count for this species was 41 in Cave D on February 21, 2013. The remaining winter observations have all been of a single bat on one occasion. However, mist-net surveys conducted at the lower entrance to the Cudjos Section documented northern long-eared bats on three occasions. On April 4, 2006, 13 individuals (3 females, 9 males, and 1 of unknown sex) were captured. On May 30, 2012, 17 males were captured exiting the cave. Many of the individuals were noted as being dirty with soil particles found on their fur or exposed skin. On June 3, 2013, 16 individuals (15 males and 1 female) were captured both exiting and entering the cave. The dirty bats suggest these individuals were roosting in the cave in areas where they could contact soil (deep crevices or under rocks) and potentially overlooked during hibernacula surveys. Three individuals were observed roosting in Indian Cave on May 30, 2012, and one individual was documented roosting in Lewis Hollow Bridge Cave on August 31, 2021. Gumbert et al. (2006) captured 10 individuals at the entrance to Cave E by mist-netting on April 13, 2006. While these records are outside the normal hibernacula survey months of January through March, male bats are known to leave hibernacula later than females and thus could have been hi-

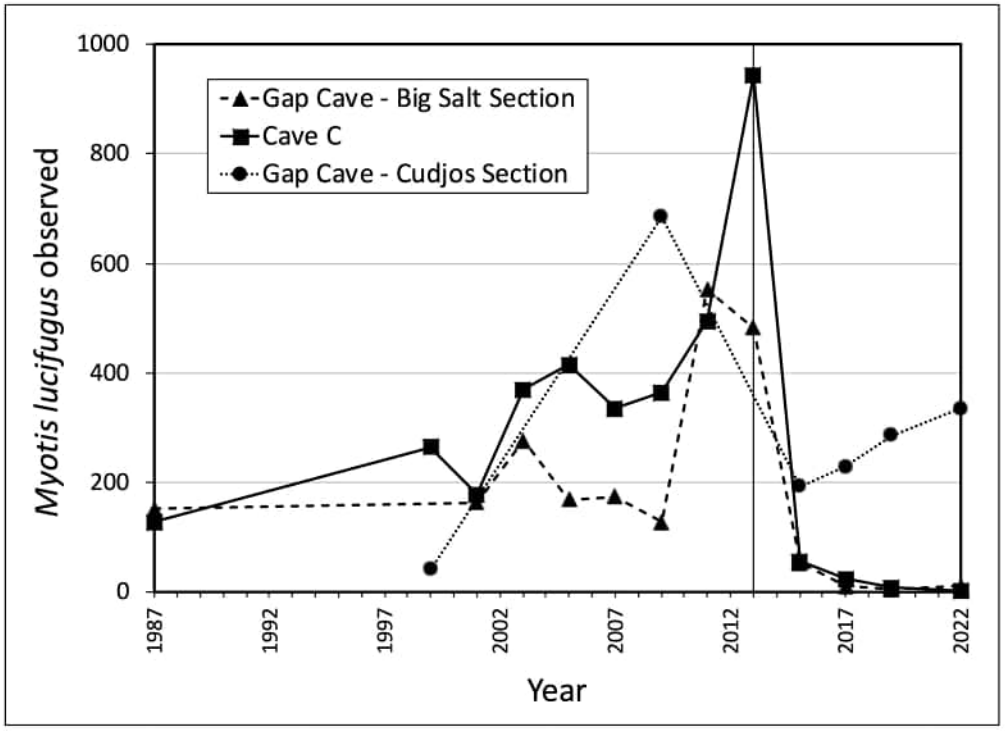


Figure 2. Little brown bat (*Myotis lucifugus*) hibernacula counts and population trend in Cumberland Gap National Historical Park. The vertical bar at 2013 indicates when white-nose syndrome was first detected in CUGA.

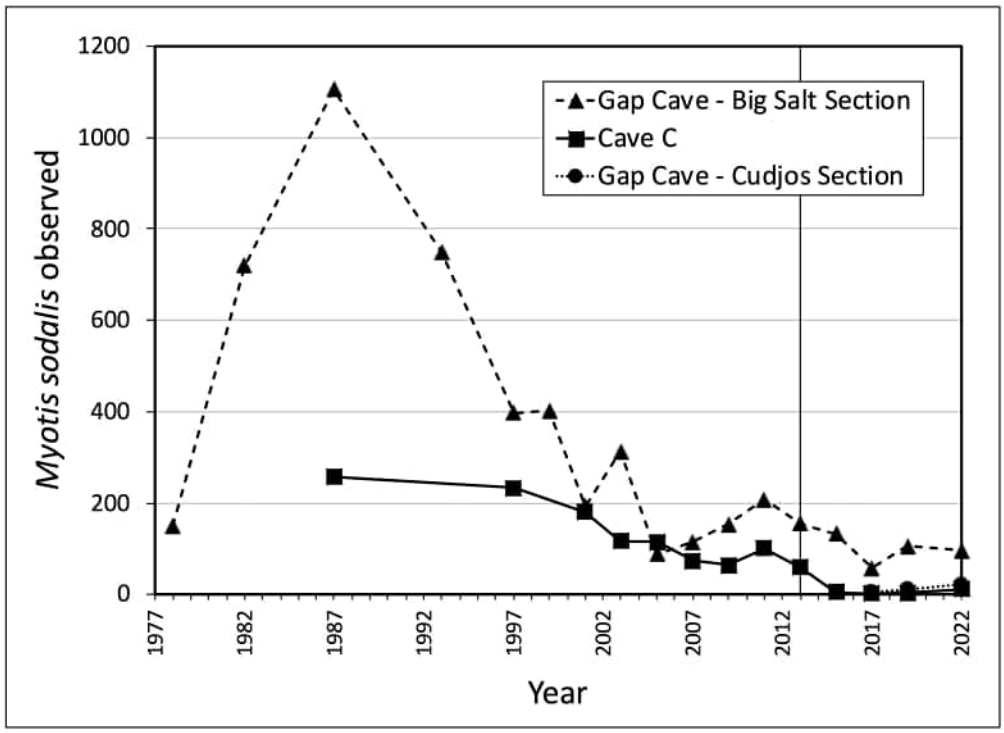


Figure 3. Indiana bat (*Myotis sodalis*) hibernacula counts and population trend in Cumberland Gap National Historical Park. The vertical bar at 2013 indicates when white-nose syndrome was first detected in CUGA.

bernating in Gap Cave or the other caves (Norquay and Willis, 2014; Czenze and Willis, 2015). While WNS impacts to the northern long-eared bat in karst habitats have been dramatic, there are populations in coastal areas and in parts of the Appalachians not in close proximity to caves or other karst features that are persisting (Jordan, 2020). Whether or not these areas persist as refugia for the northern long-eared bat will only be realized through time.

*Myotis sodalis* (Miller and Allen, 1928) – Indiana Bat
Sites known from CUGA: Gap Cave System (Big Salt and Cudjos Sections), Little Saltpeter Cave, Cave C

Indiana bats have been consistently (multiple consecutive survey years) documented at 15 caves and incidentally at 8 additional caves in Virginia, Little Saltpeter Cave being one. In the Gap Cave System, areas in the Big Salt Section near the Big Saltpetre and Saltpetre Well entrances supported one of Virginia's largest documented Indiana bat hibernating populations with a count of 1,094 individuals in 1987. While Indiana bats have been reported in the Cudjos Section near the lower entrance of Gap Cave, surveys in the 1990s failed to confirm the reports. Indiana bats were first confirmed in the Cudjos Section of Gap Cave in 2017 when five individuals were observed among clusters of little brown bats. Cave C is the other historic site in CUGA supporting hibernating Indiana bats with counts conducted back in the 1980s. After significant declines through the 1990s in CUGA, population numbers appeared to be stabilizing and slightly increasing until the onset of WNS when the populations continued to decline. Current counts since 2017 suggest a leveling of the population trend, but at a fraction of the historic high count (Figure 3).

*Perimyotis subflavus* (F. Cuvier, 1832) – Tri-colored Bat
Sites known from CUGA: Gap Cave System (Big Salt and Cudjos Sections), Indian Cave, Lewis Hollow Bridge Cave, Little Saltpeter Cave, Cave A, Cave B, Cave C, Cave D, Cave E, Cave F

Despite an overall population decline of 94.1% due to WNS, the tri-colored bat is still today the most commonly observed bat in Virginia caves. Tri-colored bats have been observed in more caves in CUGA than any other bat species. Similar to the little brown bat trend, high numbers of tri-colored bats were observed at both the Big Salt Section of Gap Cave and Cave C in 2013. These high counts were followed by significant declines in 2015 with an increasing trend stabilizing in 2022 (Figure 4).

**Mammalia - Rodentia**

*Neotoma magister* (Baird, 1858) – Allegheny Woodrat
Sites know from CUGA: Cliff Cave (new record), Gap Cave System (Big Salt and Cudjos Sections), Indian Cave (new record), Little Saltpeter Cave, Olde Formation Pit, Packrat Cave, Skylight Cave

Allegheny woodrats are a forest-dwelling species associated with cliffs, rock outcrops, talus slopes, and caves. Woodrats are frequent visitors to caves and are important importers of organic matter, in the form of nesting materials, food caches, and fecal and urine deposition, into caves. These organic nutrients are known to support a specialized invertebrate cave community (Richards, 1989; 1990). Over the last several decades there have been major population declines in the northern portion of the animal's range (Hicks, 1989; Hayes, 1990; Beans, 1992; Sciascia, 1993). Because woodrats are basically solitary and territorial, they usually do not occur in large numbers (normally 1–4) at a site. Conspic-

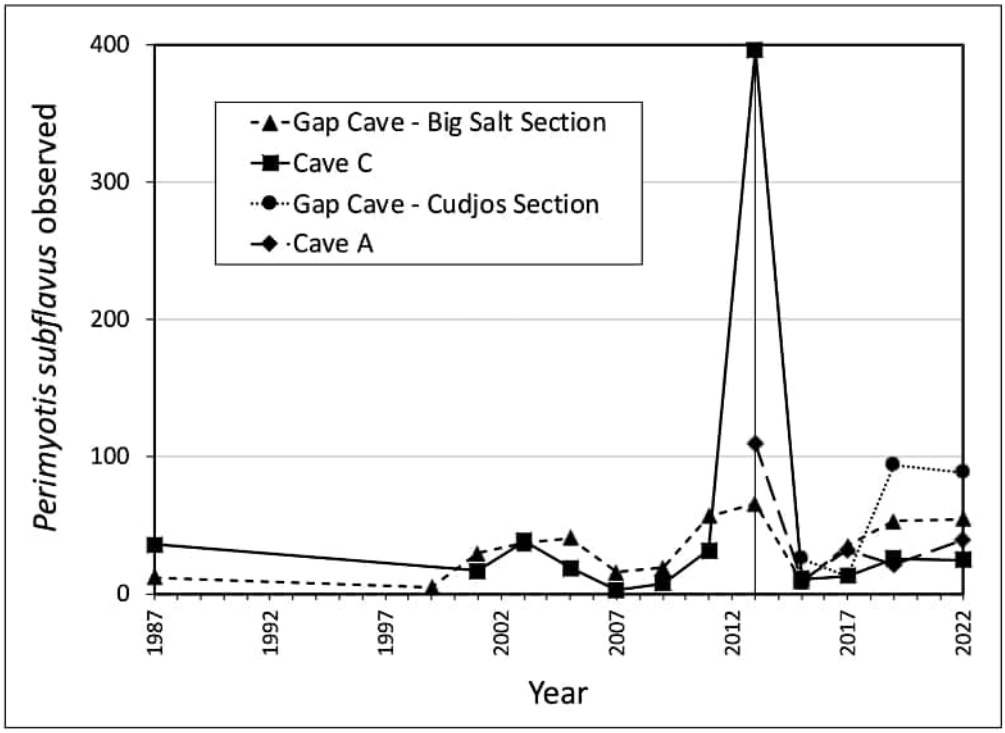


Figure 4. Tri-colored bat (*Perimyotis subflavus*) hibernacula counts and population trend in Cumberland Gap National Historical Park. The vertical bar at 2013 indicates when white-nose syndrome was first detected in CUGA.

uous fresh sign (e.g., latrines, nests, food caches) or an occasional live/dead individual of this species has been observed in several caves at CUGA. While no formal surveys have been conducted for woodrats in CUGA, anecdotal observations provide an initial overview of the distribution of woodrats in CUGA.

**Myriapoda**

*Pseudotremia fracta (Chamberlin, 1951) – A millipede*

Our records from Tiprell Spider Cave and Powell Mountain Cave in Claiborne County, Tenn. are the northernmost sites for *P. fracta*, which is known from cave and surface localities in eastern Tennessee and western North Carolina (Hoffman, 1981) and south to northwest Georgia (Zigler et al., 2020).

*Oxidus gracilis (Koch, 1847) – Greenhouse Millipede*

This introduced species is now commonly encountered in caves of the Appalachians, including in CUGA caves.

## DISCUSSION

This study broadened our understanding of cave biodiversity within CUGA. As is common in cave communities, many of the troglobionts of CUGA exhibit extreme endemism and are of significant conservation concern. Four species are endemic to the park, with three species—*Kleptochthonius lutzi*, *Lissocreagris valentinei*, and *Lirceus zigleri*—known only from Gap Cave. *Caecidotea cumberlandensis* is known from two CUGA caves and nowhere else. Three additional species have ranges that reach beyond the park borders but do not extend beyond Lee County, VA or Claiborne County, TN. Such extreme endemism helps explain the conservation status of these species—six have NatureServe Global Conservation Status ranks of G1 or Critically Imperiled (Table 2), and another (*Lirceus zigleri*) will likely be ranked G1 once evaluated. Three additional species have State Conservation Status ranks of S1 or S1S2 in Virginia.

In contrast to the troglobionts, the bats known from CUGA have ranges encompassing large portions of North America, but nearly all are of conservation concern due to a combination of long-term population declines and the recent impact of WNS. Five of the six bat species known from caves in CUGA have State Conservation Status ranks of S1 or S2 (Imperiled) in Virginia (Table 2). The Indiana bat has been listed as a federally endangered species since 1967, and its population in CUGA caves has decreased over time (Figure 3). The northern long-eared bat joined the Indiana bat on the federal Endangered Species list in 2023, as a result of precipitous population declines due to WNS (Cheng et al., 2021). The tri-colored bat was proposed for listing as federally endangered by the USFWS in September 2022 primarily due to the range-wide impacts of WNS. A final listing decision is expected in September 2023. The little brown bat is currently under review for listing on the Endangered Species list due to population declines associated with WNS (Powers et al., 2015; Cheng et al., 2021). Interestingly, the little brown bat hibernaculum in the Cudjos Section of Gap Cave has seen increasing numbers over the past decade (Figure 2).

Gap Cave is notable as a hotspot for cave biodiversity on a regional scale. With ten described troglobionts, and an as-yet-unidentified *Litocampa* sp., Gap Cave is one of only four caves in Virginia known to support 10 or more troglobionts (Christman et al., 2016). In addition, Gap Cave is the type locality for *K. lutzi*, *L. valentinei*, *Pseudanophthalmus hirsutus*, and *Pseudotremia valga*. Gap Cave is one of only two caves in Virginia that is the type locality for five troglobionts (Christman et al., 2016). Beyond the troglobionts, six bat species are known from Gap Cave, and it supports the largest population of federally endangered Indiana bats in CUGA.

Further biosurvey work in Gap Cave is recommended, as it is likely that troglobionts known from other caves in CUGA but not yet recorded from Gap Cave will be observed. Species likely to be recorded from Gap Cave are *Hesperochernes mirabilis*, *Stygobromus cumberlandus*, *Caecidotea cumberlandensis*, *Pogonognathellus danieli*, and *Spelobia tenebrarum*. This would help to fill out the picture of cave biodiversity in Gap Cave. In addition, further study of the distribution, population density, and life history of *Lirceus zigleri* in the Gap Cave stream would improve our understanding of this newly discovered single-cave endemic. The long-term, standardized bat monitoring that has been done for decades in CUGA provides critical information about population trends that can inform management decisions and conservation plans for these increasingly threatened animals.

CUGA hosts significant cave biodiversity. Many of the species known from park caves are of conservation concern, including several species that are endemic to the park. Gap Cave is notable as one of the most biodiverse caves in Virginia, and it is likely that additional biosurveys in Gap Cave will detect even more species. CUGA supports some of the most biodiverse cave communities on National Park Service property, providing critical habitat to two groups of species facing distinct conservation concerns—poorly known troglobionts that exhibit extreme endemicity and bats under threat from WNS.

## ACKNOWLEDGMENTS

This project would not have been possible without the guidance and assistance of Jenny Beeler of CUGA. She secured the funding, guided our planning, managed our permitting, and facilitated the field work. Kurt Helf shared unpublished data. Additional assistance in the field was provided by Terri Brown, Evin Carter, Lindsey Hayter, Adam Jones, Vincent Leray, Nathaniel Mann, and Cheryl Pratt. Pollyanne Frantz assisted with grant oversight and reporting. The Virginia Speleological Survey shared maps of CUGA caves. This project was supported by a grant from the Southern Appalachian Cooperative Ecosystem Studies Unit. Funding for bat hibernacula surveys was provided by Virginia Department of Wildlife Resources through a Wildlife Restoration Program Grant from the USFWS. Levi Trumbore was supported by an Undergraduate Fellowship in Karst Studies from the Cave Conservancy Foundation. Field work was permitted by the National Park Service (Permit # CUGA-2016-SCI-0011), the Virginia Department of Game and Inland Fisheries (Permit # 058511), the Tennessee Wildlife Resources Agency (Permit # 1385), and the Virginia Cave Board.

## REFERENCES

Barnes, J.K., Slay, M.E., and Taylor, S.J., 2009, Adult diptera from Ozark caves: Proceedings of the Entomological Society of Washington, v. 111, p. 335–353. https://doi.org/10.4289/0013-8797-111.2.335

Beans, B.E., 1992. Without a trace: the puzzling demise of the Allegheny woodrat: Audubon, v. 92, p. 32–34.

Blehert, D. S., Hicks, A.C., Behr, M., Meteyer, C.U., Berlowski-Zier, B.M., Buckles, E.L., Coleman, J.T., Darling, S.R., Gargas, A., Niver, R., and Okoniewski, J.C., 2009. Bat white-nose syndrome: an emerging fungal pathogen?: Science, v. 323, p. 227. https://doi.org/10.1126/science.1163874

Caceres, M.C., and Barclay, R.M.R., 2000, *Myotis septentrionalis*: Mammalian Species, v. 634, p. 1–4. https://doi.org/10.1644/1545-1410(2000)634<0001:MS>2.0.CO;2

Cheng, T.L., Reichard, J.D., Coleman, J.T., Weller, T.J., Thogmartin, W.E., Reichert, B.E., Bennett, A.B., Broders, H.G., Campbell, J., Etchison, K., and Feller, D.J., 2021, The scope and severity of white-nose syndrome on hibernating bats in North America: Conservation Biology, v. 35, p. 1–12. https://doi.org/10.1111/cobi.13739

Christman, M.C., Doctor, D.H., Niemiller, M.L., Weary, D.J., Young, J.A., Zigler, K.S., and Culver, D.C., 2016, Predicting the occurrence of cave-inhabiting fauna based on features of the earth surface environment: PloS One, v. 11, p. e0160408. https://doi.org/10.1371/journal.pone.0160408

Christman, M.C. and Culver, D.C., 2001, The relationship between cave biodiversity and available habitat: Journal of Biogeography, v. 28, p. 367–380. https://doi.org/10.1046/j.1365-2699.2001.00549.x

Christman, M.C., Culver, D.C., Madden, M.K., and White, D., 2005, Patterns of endemism of the eastern North American cave fauna: Journal of Biogeography, v. 32, p. 1441–1452. https://doi.org/10.1111/j.1365-2699.2005.01263.x

Cryan, P.M., Meteyer C.U., Boyles, J.G., and Blehert, D.S., 2010, Wing pathology of white-nose syndrome in bats suggests life-threatening disruption of physiology: BMC Biology, v. 8, p. 135. https://doi.org/10.1186/1741-7007-8-135.

Culver, D.C., Master, L.L., Christman, M.C., and Hobbs III, H.H., 2000, Obligate cave fauna of the 48 contiguous United States: Conservation Biology, v. 14, p. 386–401. https://doi.org/10.1046/j.1523-1739.2000.99026.x

Czenze, Z.J. and Willis, C.K.R., 2015, Warming up and shipping out: arousal and emergence timing in hibernating little brown bats (*Myotis lucifugus*): Journal of Comparative Physiology B, v. 185, p. 575–586. https://doi.org/10.1007/s00360-015-0900-1

Felderhoff, K.L., Bernard, E.C., and Moulton, J.K., 2010, Survey of *Pogonognathellus* Börner (Collembola: Tomoceridae) in the Southern Appalachians based on morphological and molecular data: Annals of the Entomological Society of America, v. 103, p. 472–491. https://doi.org/10.1603/AN09105

Gertsch, W.J., 1984, The spider family Nesticidae (Araneae) in North America, Central America, and the West Indies: Texas Memorial Museum, The University of Texas at Austin. https://archive.org/details/tmm-0082-3074-bulletin-31/mode/2up.

Gumbert, M., Sewell, P., and Roby, P., 2006, Mammals of Cumberland Gap National Historical Park; Kentucky, Tennessee, Virginia: Copperhead Consulting, Richmond, Kentucky.

Hayes, J.P., 1990, Biogeographic, systematic, and conservation implications of geographic variation in woodrats of the eastern United States [Ph.D. dissertation]: Ithaca, N.Y, Cornell University.

Hicks, A., 1989, The decline and fall of a native New Yorker: Whatever happened to the Allegheny woodrat?: The Conservationist, v. 43, p. 34–38.

Hicks, A., Herzog, C., Ballmann, A., and King, A., 2009, Protocol for 2008-2009 hibernacula surveys of cave bats: U.S. Fish and Wildlife Service Report. 45 p. ,https://nysl.ptfs.com/#!/s?a=c&q=*&type=16&criteria=field11%3D50874345~~browse6_ss%3D%221989%22&b=0.

Hoffman, R.L., 1981, On the taxonomic status, distribution, and subspecies of the milliped *Pseudotremia fracta* Chamberlin (Chordeumatida, Cleidogonidae): Brimleyana, v. 5, p. 135–144. https://archive.org/details/brimleyana51981.

Holsinger, J.R. and Culver, D.C., 1988, The invertebrate cave fauna of Virginia and a part of Eastern Tennessee: Zoogeography and Ecology: Brimleyana, v. 14, p. 1–162. https://archive.org/details/brimleyana141988.

Holsinger, J.R., Culver, D.C., Hubbard Jr., D.A., Orndorff, W.D., and Hobson, C.S., 2013, The invertebrate cave fauna of Virginia: Banisteria, v. 42, p. 9–56. https://archive.org/details/banisteria42virg/banisteria42virg/.

Hubbell, T.H. and Norton, R.M., 1978, The systematics and biology of the cave-crickets of the North American tribe Hadenoecini (Orthoptera: Saltatoria: Ensifera: Rhaphidophoridae: Dolichopodinae): Misc. Papers of the Museum of Zoology, University of Michigan, v. 156, p. 1–124. https://deepblue.lib.umich.edu/handle/2027.42/56400.

Huber, B.A., 2011, Revision and cladistic analysis of *Pholcus* and closely related taxa (Araneae, Pholcidae): Bonner Zoologische Mongraphien, v. 58, p. 1–509. https://www.researchgate.net/publication/233733114_Revision_and_cladistic_analysis_of_Pholcus_and_closely_related_taxa_Araneae_Pholcidae/link/0912f50ae2263d3292000000/download.

Jordan, G., 2020, Status of an Anomalous Population of Northern Long-Eared Bats in Coastal North Carolina: Journal of Fish and Wildlife Management, v. 11, p. 665–678. https://doi.org/10.3996/JFWM-20-018

Koenemann, S. and Holsinger, J.R., 2001, Systematics of the North American subterranean amphipod genus *Bactrurus* (Crangonyctidae): Beaufortia, v. 51, p. 1–56. https://archive.org/details/beaufortia-51-001-056.

Lewis, J.J., 2000, *Caecidotea cumberlandensis*, a new species of troglobitic isopod from Virginia, with new records of other subterranean *Caecidotea* (Crustacea: Isopoda: Asellidae): Proceedings of the Biological Society of Washington, v. 113, p. 458–463. https://ia801306.us.archive.org/6/items/biostor-81039/biostor-81039.pdf.

Lewis, J.J., Lewis, S.L., Orndorff, W., Orndorff, Z., Malard, F., Konecny-Dupré, L., Saclier, N., and Douady, C., 2023, The Groundwater Isopods of Virginia (Isopoda: Asellidae and Cirolanidae): Special Publication #19, Virginia Museum of Natural History, 214 p.

Marshall, S.A. and Peck, S.B., 1984, Distribution of cave-dwelling Sphaeroceridae (Diptera) of eastern North America: Proceedings of the Entomological Society of Ontario, v. 115, p. 37–41. https://www.biodiversitylibrary.org/item/139960#page/47/mode/1up.

Matthews, L.E. 2008, Caves of Knoxville and the Great Smoky Mountains: National Speleological Society, Huntsville, Alabama, 296 p.

Niemiller, M.L. and Zigler, K.S., 2013, Patterns of cave biodiversity and endemism in the Appalachians and Interior Plateau of Tennessee, USA: PLoS One, v. 8, e64177. https://doi.org/10.1371/journal.pone.0064177

Niemiller, M.L., Taylor, S.J., and Bichuette, M.E., 2018, Conservation of cave fauna, with an emphasis on Europe and the Americas, *in* Moldovan, O.T., Kováč, L., and Halse, S., eds., Cave Ecology, Cham, Switzerland, Springer. p. 451–478. https://doi.org/10.1007/978-3-319-98852-8_22

Norquay, K.J.O. and Willis, C.K.R., 2014, Hibernation phenology of *Myotis lucifugus*: Journal of Zoology, v. 294, p. 85–92. https://doi.org/10.1111/jzo.12155

Powers, K.E., R.J. Reynolds, R.J., Orndorff, W., Ford, W.M., and Hobson, C.S., 2015, Post-white-nose syndrome trends in Virginia's cave bats, 2008−2013: Journal of Ecology and the Natural Environment, v. 7, p. 113–123. https://doi.org/10.5897/JENE2015.0507

Richards, P., 1989, Predation in the cave rat fecal latrine: Cave Research Foundation Annual Report, Cedar Falls, Iowa. p. 45–47. https://www.cave-research.org/annual_reports/crf_ar_1989.pdf.

Richards, P., 1990, The effects of predation on invertebrate community structure in the cave rat fecal latrine: Cave Research Foundation Annual Report, Cedar Falls, Iowa, p. 58–61. https://www.cave-research.org/annual_reports/crf_ar_1990.pdf.

Sciascia, J.C., 1993, Raccoons may be linked to eastern woodrat decline: Nongame News, New Jersey Endangered and Nongame Species Program, Trenton, NJ.

Shear, W.A., 2011, Cave millipeds of the United States. X. New species and records of the genus *Pseudotremia* Cope: 2. Species from Virginia, USA (Diplopoda, Chordeumatida, Cleidogonidae): Zootaxa, v. 3109, p. 1–38. https://doi.org/10.11646/zootaxa.3109.1.1

Whitaker, J.O., Jr, 1992, Winter activity of bats at a mine entrance in Vermillion County, Indiana: The American Midland Naturalist, v. 127, p. 50–59. https://doi.org/10.2307/2426321

Zhang, J. and Holsinger, J.R., 2003, Systematics of the freshwater amphipod genus *Crangonyx* in North America: Virginia Museum of Natural History, Memoir, v. 6, p. 1–274.

Zigler, K.S., Niemiller, M.L., Stephen, C.D., Ayala, B.N., Milne, M.A., Gladstone, N.S., Engel, A.S., Jensen, J.B., Camp, C.D., Ozier, J.C., and Cressler, A., 2020, Biodiversity from caves and other subterranean habitats of Georgia, USA: Journal of Cave and Karst Studies, v. 82, p. 125–167. https://doi.org/10.4311/2019LSC0125