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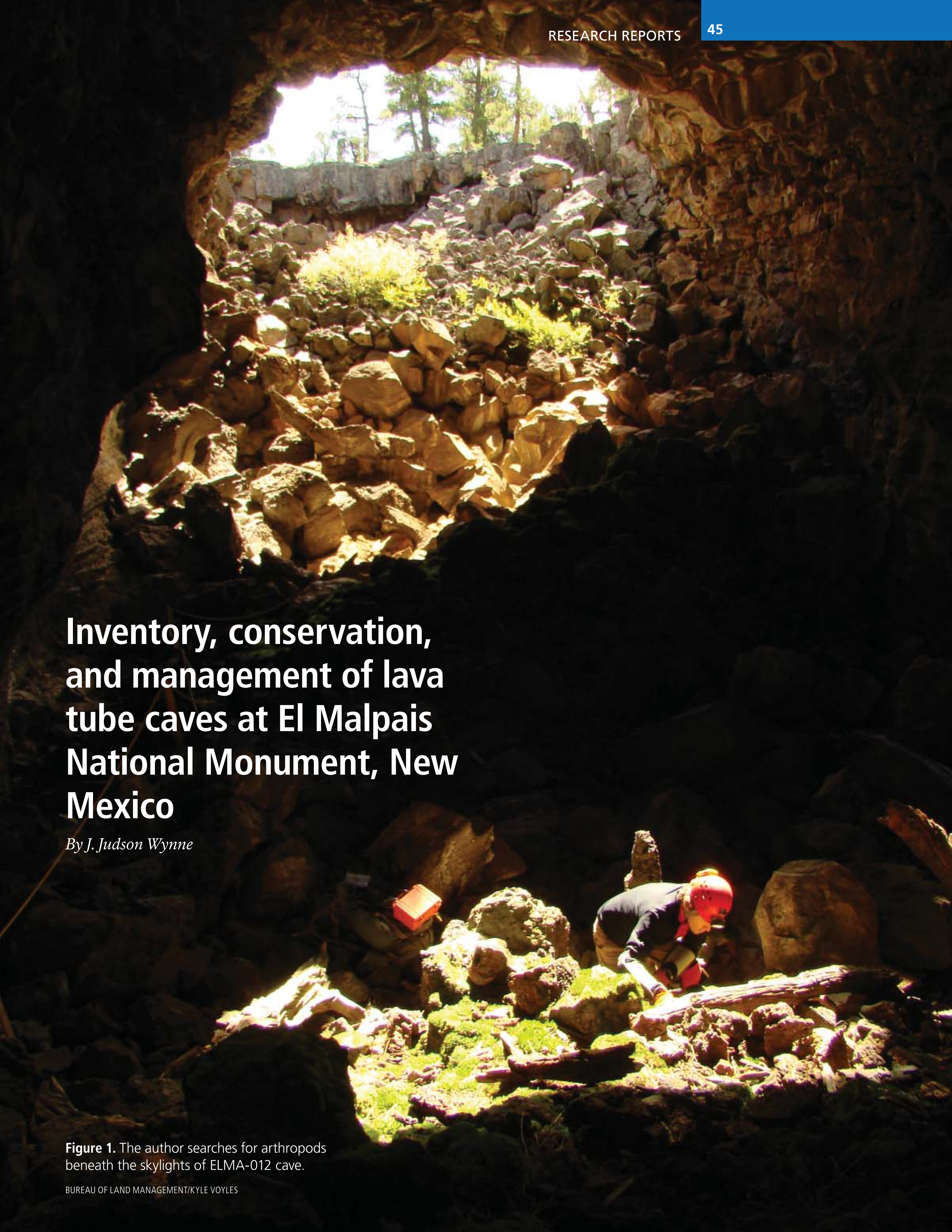
Inventory, conservation, and management of lava tube caves at El Malpais National Monument, New Mexico

J. Judson Wynne



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By J. Judson Wynne

Figure 1. The author searches for arthropods beneath the skylights of ELMA-012 cave.

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Abstract
Lava tube caves at El Malpais National Monument have received little scientific attention with regard to their bat and arthropod populations. From an all taxa biological inventory of 11 caves, I identified seven new species of cave-dwelling arthropods (including two potential troglobites) and range expansions of two parasitoidal wasps. The presence of unique microhabitats, tree root "curtains" hanging from the ceilings, and moss gardens in cave entrances resulted in higher species richness of arthropods at four caves. For bats, I confirmed continued use of one large bat hibernaculum cave and one significant bat maternity roost. While several recommendations have been made to better conserve and manage sensitive cave resources, additional research and monitoring will be required for the long-term management and protection of several caves. Finally, I introduce three new terms to cave biology: two for entrance-dwelling animals (eisodophiles and eisodoxenes) and one for animals that hunt deep within or near the entrances of caves (xenosylles).

Key words
cave, cave biology, cave-dwelling arthropods, cave-roosting bats, conservation, eisodophile, eisodoxene, El Malpais National Monument, land management, lava tubes, xenosylle

LOCATED IN WESTERN NEW MEXICO, EL MALPAIS National Monument encompasses approximately 1,522 km² [~588 mi²]. Featuring at least eight major volcanic eruptions ranging in age from 100,000 to 3,000 years old (Cascadden et al. 1997), the national monument is a dramatic landscape comprising vast expanses of pahoehoe and ʻaʻā lava flows, cinder cones, ice caves, and at least 290 lava tube caves (fig. 1, previous page). Despite the large number of lava tube caves, this region has received little scientific attention with regard to bat and arthropod populations that occur within these features.

Bats are often considered keystone species of cave ecosystems. When bats populate caves in large numbers, they transport a significant amount of organic material (as guano) from the surface into the cave. Although bats have been studied throughout most of the western United States, how these animals use caves remains underresearched. Bat maternity roosts (sites where female bats rear their pups) and hibernacula (winter hibernation sites) are highly sensitive to human disturbance (Brown et al. 1993; McCracken 1989; Elliott 2000; Hamilton-Smith and Eberhard 2000). With the westward advance of white-nose syndrome, a disease responsible for the mortality of more than five million bats in eastern North America (USFWS 2012), inventory and monitoring of all roost sites will be critically important to the long-term management of bats at El Malpais National Monument.

Other animals of high conservation and management value are arthropods that occur exclusively in caves. Prior to this study, at least five cave-adapted arthropods (presumed sensitive species) were known from six lava tube caves at El Malpais (Northup and Welbourn 1997). Many troglomorphic (cave-adapted) animals are endemic to a single cave or region (Reddell 1994; Culver et al. 2000; Christman et al. 2005) and are generally characterized by low population numbers (Mitchell 1970). Additionally, numerous human-induced impacts threaten subterranean ecosystem health and the very persistence of cave-obligate species. Many cave-obligate species are therefore considered imperiled. Nonnative species introductions (Elliott 1992; Reeves 1999; Taylor et al. 2003; Howarth et al. 2007), global climate change (Chevaldonné and Lejeune 2003; Badino 2004), and recreational use (Culver 1986; Howarth and Stone 1993; Pulido-Bosch et al. 1997) are among the impacts that present challenges for the long-term management of cave-obligate arthropod populations at El Malpais.

An all taxa biological inventory focusing on bats, cave-dwelling arthropods, and other vertebrates was not only important to characterizing the fauna that use El Malpais lava tubes, but also was required to provide resource managers with the information necessary to best conserve and manage these sensitive resources. My objectives for this study were to (1) catalog all taxa using caves, including the identification of endemic and sensitive cave-adapted invertebrates, (2) apply and examine a systematic sampling protocol for inventorying arthropods, (3) draw comparisons across the national monument to gain inference into patterns of invertebrate species distributions, biodiversity, biogeography, and endemism, and (4) provide recommendations to enhance management of El Malpais lava tube caves. I addressed objectives 1 and 4 in this article and will address objectives 2 and 3 in subsequent publications.

Methodology

During 7–15 October 2007 and 8–15 October 2008, research teams and I conducted two site visits per cave at 10 caves at El Malpais National Monument and 1 cave on adjacent Bureau of Land Management lands. We scheduled site visits around deployment and collection of baited pitfall traps for sampling cave-dwelling arthropods. At the monument's request, I used cave codes rather than actual cave names for all caves on National Park Service lands. A copy of this report, which includes a table of cave names with associated cave codes, is on file with monument headquar-

ters in Grants, New Mexico, and the National Cave and Karst Research Institute, Carlsbad, New Mexico.

Arthropod sampling

I used both opportunistic and systematic sampling to search for arthropods. During each cave visit, a team of three researchers uniformly applied three techniques: opportunistic collecting, baited pitfall trapping, and timed searches. For opportunistic collecting, the team collected invertebrates encountered as they walked between sampling stations while deploying and removing pitfall traps and conducting timed searches.

Because I wanted to maximize the number of invertebrate species detected, we sampled each cave from its entrance (i.e., drip line) to the back of the cave. Using available cartographic cave maps, teams applied an interval sampling approach whereby 10% of each cave's length was used as the sampling interval (e.g., for a 100 m–long cave [328 ft], sampling interval was every 10 m [33 ft]). All sampling stations were plotted on each cave map. Three sampling stations (one at either wall and one at the cave centerline) were established at each sampling interval. Fewer than three sampling stations per sampling interval were established in only two cases: (1) when the cave passageway width was ≤5 m (16 ft), one station was designated in the best available location and (2) when exposed lava floors were encountered and no materials were available to aid in countersinking the trap, the sampling station was skipped.

At each sampling station we deployed one pitfall trap and conducted two timed searches. Traps consisted of two 907 g (32 oz) plastic containers (13.5 cm high, 10.8 cm diameter rim, and 8.9 cm base [5.3 in high, 4.3 in diameter, 3.5 in base]) placed inside one another, with bait (a teaspoon of peanut butter) placed in the outer container and holes punched in the base of the inner container. This design attracts arthropods and keeps most animals separated from the bait. With the assistance of field technicians, I buried containers to the rim where possible, built rock ramps to the trap rim in other cases, and covered all traps with a caprock. The team conducted timed searches within a 1 m (3.3 ft) radius of each pitfall trap station for a period of 1 to 3 minutes before traps were deployed and prior to checking traps (modified from Peck 1976). Each search was concluded after 1 minute if no arthropods were detected and continued for a total of 3 minutes when arthropods were observed.

Because some caves contain unique microhabitats that support distinct arthropod communities and endemic populations, I augmented this sampling protocol by conducting direct intuitive searches in those areas. Unique microhabitats at El Malpais include moss gardens (refer to Northup and Welbourn 1997) at cave entrances and beneath skylights (i.e., holes in the ground formed by the partial collapse of the cave roof), and tree root "curtains" hanging from the ceilings in cave deep zones (fig. 2). Within each unique microhabitat we spent one hour (3 observers × ~20 minutes) searching for arthropods. Specifically, we searched tree root curtains hanging from the ceilings in two caves (one hour per cave) and moss gardens in two caves (one hour per cave).

Figure 2. Both moss gardens (top row) and root curtains (bottom row) are important microhabitats and support new and unique arthropod species. At least three lava tube caves contain moss gardens within cave entrances and beneath skylights, and two caves contain plant root curtains within cave deep zones at El Malpais National Monument.

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Arthropod identification

For arthropod groups actively being studied by taxonomic specialists, I sent either specimens or high-resolution images of specimens to various taxonomic experts for identification. Otherwise, we used existing keys to identify specimens to the lowest taxonomic level possible.

Bat sampling

I visited and inventoried three known bat roosts: a Mexican free-tailed bat (*Tadarida brasiliensis*) maternity colony, a Townsend's big-eared bat (*Corynorhinus townsendii*) maternity roost, and a Townsend's big-eared bat hibernaculum. Additionally, for sites where bat use was unknown, these caves were surveyed for midfall use by bats. Research teams scanned ceilings and walls throughout the length of each cave, and searched for any evi-

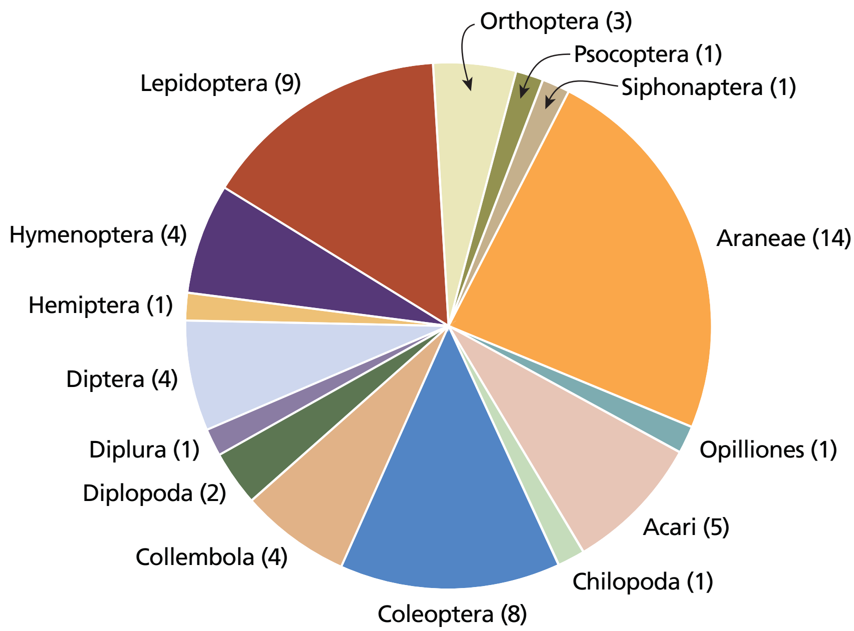

Figure 3. Number of arthropod morphospecies detected by order (including classes Chilopoda and Diplopoda) at El Malpais National Monument in 2007 and 2008. The surveys were conducted at 11 caves: ELMA-062, ELMA-008, ELMA-110, ELMA-262, ELMA-012, ELMA-054, ELMA-029, ELMA-303, ELMA-315, ELMA-061, and Hummingbird.

dence of bats (e.g., guano). When bats were encountered, I attempted to identify them to species visually. No bats were handled during this study.

Documenting other vertebrates

Within each cave, I searched for and recorded the presence of all other vertebrate species. Sign of other vertebrates included direct observation, scat, feathers, and skeletal remains.

Cave specificity functional groups

I divided El Malpais cave-dwelling taxa into nine cave specificity functional groups. The following functional group terminology was taken from Barr (1968) and Howarth (1983): (1) *troglobites*, obligate cave dwellers who can only complete their life cycle within the cave environment; (2) *troglophiles*, species that occur facultatively within caves and complete their life cycles there, but also exist in similar surface microhabitats; (3) *trogloxenes*, taxa that frequently use caves for shelter but forage on the surface; and (4) *accidentals*, morphospecies occurring within caves, but which cannot survive within the cave environment. Additionally, because this project sampled cave entrances for arthropods and documented other vertebrate (i.e., non-bat taxa) use of caves, I propose three additional groups for categorizing cave-dwellers: (5) *eisodophiles*, species facultatively using cave entrances and twilight zones (areas where light faintly penetrates into the cave, but is sufficient for humans to see) that may complete their life cycles there, but also occur in similar partially sheltered surface environments; (6) *eisodoxenes*, animals that frequently use cave entrances and twilight zones for shelter but return to the surface to forage; and (7) *xenosylles*, surface-dwelling animals that hunt deep within caves or in the cave entrances. For eisodophiles and eisodoxenes, the etymology of the first half of the terms, *eísodo*, is from the Greek word *eísodos*, "entrance," while the second halves were derived from the same naming convention used for functional groups 2 and 3: *philos*, Greek for "love" or "desire," and *xenos*, Greek for "guest." *Xenosylle* is a combination of *xenos* and *sylléktis*, Greek for "collector." Finally, (8) *parasites*, the special-case group, describes parasitic arthropods detected in caves due to the presence of their host (e.g., bats or other vertebrates); and (9) *unknown* is used for animals for which information is lacking to reasonably place them in one of the eight other groups.

Results

My work resulted in the identification of at least 66 morphospecies (groups distinguished from others based upon morphological characteristics), including 59 arthropods (representing at least 13 orders and two classes; fig. 3), three bats, and four other vertebrates. Appendix A, available online at http://www.nature.nps.gov/ParkScience/archive/PDF/Article_PDFs/ParkScience30(1)Summer2013_A1–A12_Wynne_3653.pdf, shares the entire list of inventoried species and provides explanations for cave specificity functional group designations.

Arthropods

Cave specificity functional groups for arthropods consisted of one troglobite, two questionable troglobites, five troglophiles, 18

questionable troglophiles, seven trogloxenes, one questionable trogloxene, one accidental, 21 eisodophiles, one parasite, and two unknowns (fig. 4). At least seven new species were discovered and two range expansions were documented. New species discoveries include one potentially cave-adapted spider (family Theridiidae, *Theridion* n.sp.?); a mite (family Histiostomatidae, *Histiostoma* n.sp.); two springtails (order Collembola, *Drepanura* n.sp. and *Pogonognathellus* n.sp.); one new cricket species (*Ceuthophilus* cf *apache* n.sp.); one beetle (family Carabidae, *Rhadine* n.sp., *perlevis* species-group); and a new species of potentially cave-adapted planthopper (order Hemiptera: superfamily Fulgoroidea; Fulgoroidea n.sp.?; refer to fig. 5 for images of select new species). Additionally, I confirmed the persistence of the troglomorphic bristletail (order Diplura: family Campodeidae; Campodeidae n.sp.) within the deep zone of ELMA-054. Northup and Welbourn (1997) identified this as both a troglobite and an "undetermined species." Working with dipluran taxonomist Dr. R. Thomas Allen (Academy of Natural Sciences, Drexel University, Philadelphia, Pennsylvania), we confirmed this animal as a new species in 2013. The likely new species of planthopper was detected within the cave deep zones on roots protruding from the ceiling of ELMA-315 and ELMA-303; this animal has reduced eyes in its nymphal stage and may be troglomorphic. Also, this work resulted in the range expansions of two species of parasitoidal wasps (fig. 6, next page) (family Tiphiidae, *Tiphia andersoni* and *T. nona*; Allen 1971). Both tiphiids were in a torpor and collected from beneath rocks within the moss gardens of ELMA-008 and ELMA-012. Given the season (midfall) and their behavior, I suggest these wasps may have been preparing to hibernate within the moss gardens.

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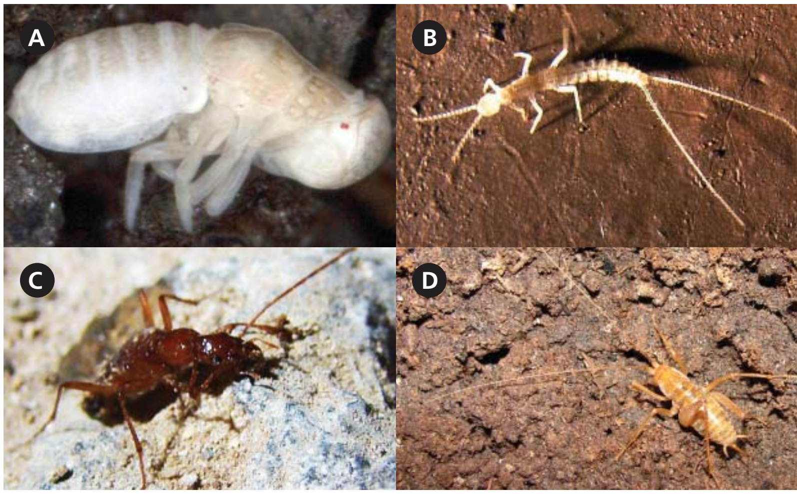
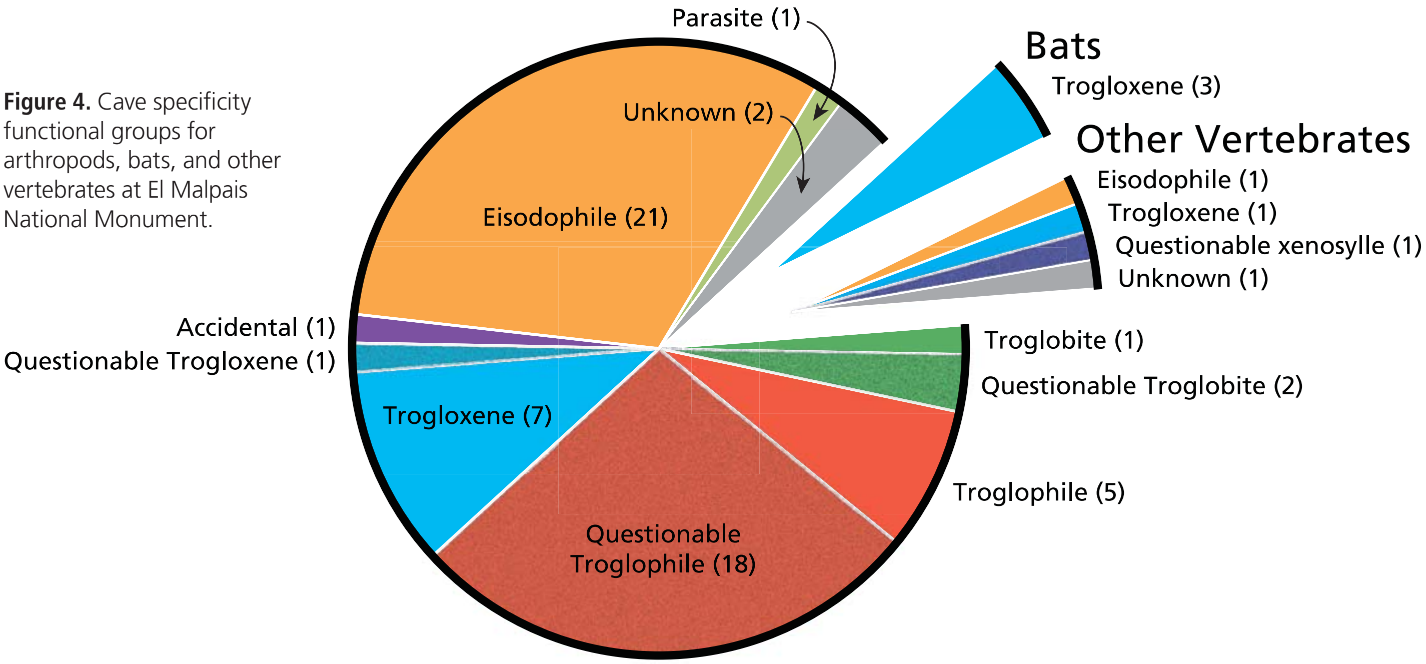


Figure 5. (A) New species of a potentially troglobitic planthopper (order Hemiptera: superfamily Fulgoroidea: Fulgoroidea n.sp.?; body length ~1.5 mm); (B) new species of troglobitic bristletail (order Diplura: family Campodeidae; from Northup and Welbourn 1997; length 2.5 mm); (C) new species of trogloxenic Carabid beetle (*Rhadine* n.sp., *perlevis* species-group; length 15 mm); and (D) new species of trogloxenic cave cricket (*Ceuthophilus* cf *apache* n.sp.; length 25 mm).

Figure 4. Cave specificity functional groups for arthropods, bats, and other vertebrates at El Malpais National Monument.



Caves with the highest arthropod species richness, in rank order, were ELMA-315 (n = 22), ELMA-012 (n = 16), ELMA-303 (n = 15), ELMA-008 (n = 15), ELMA-062 (n = 13), and ELMA-262 (n = 11) (table 1). ELMA-315 and ELMA-303, which had the highest species richness, contain extensive root curtains protruding through ceiling fissures within the cave deep zones. For ELMA-012 and ELMA-008, richness is driven by the large number of species detected within moss gardens at cave entrances and beneath skylights. ELMA-062 supports a large Mexican free-tailed bat maternity roost; because significant nutrients via guano have been transported into this cave, this likely contributed to the high number of morphospecies. In 2007, logistical constraints prevented my team from sampling the moss gardens within the entrance of ELMA-029 and from further sampling ELMA-110 (which supports a bat maternity roost). Thus, I suggest both of these caves likely support more arthropods (in terms of richness and abundance) than are included in this report.

All new species reported here were identified as "new" by taxonomic specialists. Several of these new species ultimately will be formally described and the results published in scientific journals.

Figure 6. *Tiphia andersoni* Allen, 1971. This specimen was collected via a direct intuitive search of moss gardens (beneath the large skylights) of ELMA-012. Prior to this work, this parasitoidal wasp was known to occur in central Mexico, north into southeastern and north-central Arizona (Allen 1971). Detection of this animal in New Mexico represents an expansion of its known range.

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Bats

During the 2007 surveys, I observed five hibernating Townsend's big-eared bats in the deep zone of ELMA-054 and one torpid big brown bat (*Eptesicus fuscus*) roosting near the entrance (figs. 7A and 7B, respectively). Additionally, ELMA-062 continues to support a maternity colony of Mexican free-tailed bats. On 10 October 2007, I observed thousands of individuals of this species roosting approximately 75 m (246 ft) within the cave (fig. 7C); however, when I returned four days later to remove arthropod traps, that number dropped to less than 100. Also in October 2007, I did not observe any Townsend's big-eared bats in residence at ELMA-110; once I arrived, this roost was already abandoned for the year. Relatively fresh guano in the main section of the cave (beginning at the northeasternmost skylight, extending to the northeastern ward) suggests they were using this area before they relocated to their winter roosts. During an unrelated study in 2005 and 2006, I observed a maternity roost of this species in both the main cave and tunnel segments directly southwest of the main section of this cave. It seems the colony uses several areas in the tunnel segments and within the main cave passageway during the breeding season. Given the sampling period in early October (after breeding), I was unable to ascertain whether or not additional summer roosts exist on the national monument. However, aside from the two known maternity roosts, I did not observe any significant deposits of fresh guano (suggestive of a large summer roost) in any of the other caves. Thus, I have no evidence to suggest additional large summer roosts occur in the caves sampled. All bats were considered trogloxenes.

Other vertebrates

I documented small-carnivore (questionable xenosylle) scat, likely ringtail (*Bassariscus astutus*), skunk (*Conepatus* sp.), or raccoon (*Procyon lotor*), in ELMA-054 and ELMA-110. Skunks and raccoons often prey upon infirm bats or bat pups that have fallen from the ceiling (Winkler and Adams 1972), and ringtails are commonly known to hunt bats roosting on cave walls. I found a fully articulated ringtail skeleton near the terminus of the northern extent of ELMA-303. I sent photographs of the skeleton to Eastern Tennessee State University paleontologist Dr. Jim Mead. In an e-mail exchange with him on 4 March 2013, he suggested the remains were between 1,000 and 10,000 years old. This animal may have entered the cave to hunt bats, became disoriented, and, unable to find its way back to the entrance, died in the cave. Given its age, I did not consider this animal's remains as part of this inventory. Recent packrat (*Neotoma* sp.; *N. mexicana* and/or *N. albigula*; refer to Bogan et al. 2007) activity was evident in both ELMA-062 and ELMA-061; packrats are considered trogloxenes. Also, I found the carcass of a gopher snake (*Pituophis catenifer*) in the twilight zone of ELMA-061. The snake was wrapped around

Table 1. Observed morphospecies richness for arthropods, bats, and other vertebrates at El Malpais National Monument caves

Cave	Arthropods	Bats	Other Vertebrates
[μ]ELMA-008	15	—	—
[μ]ELMA-012	16	—	—
ELMA-029	—	—	—
[β]ELMA-054	2	2	1
ELMA-061	1	—	2
[β]ELMA-062	13	1	1
[β]ELMA-110	4	1	—
[μ]ELMA-262	11	—	1
[ρ]ELMA-303	15	—	—
[ρ]ELMA-315	22	—	—
Hummingbird	3	—	—

Notes: Some species were detected in two or more caves.
[μ]Moss gardens occurred beneath skylights and within entrances of these caves.
[β]Confirmed bat roosts.
[ρ]Caves with extensive root curtains protruding through the ceiling within the deep zone.

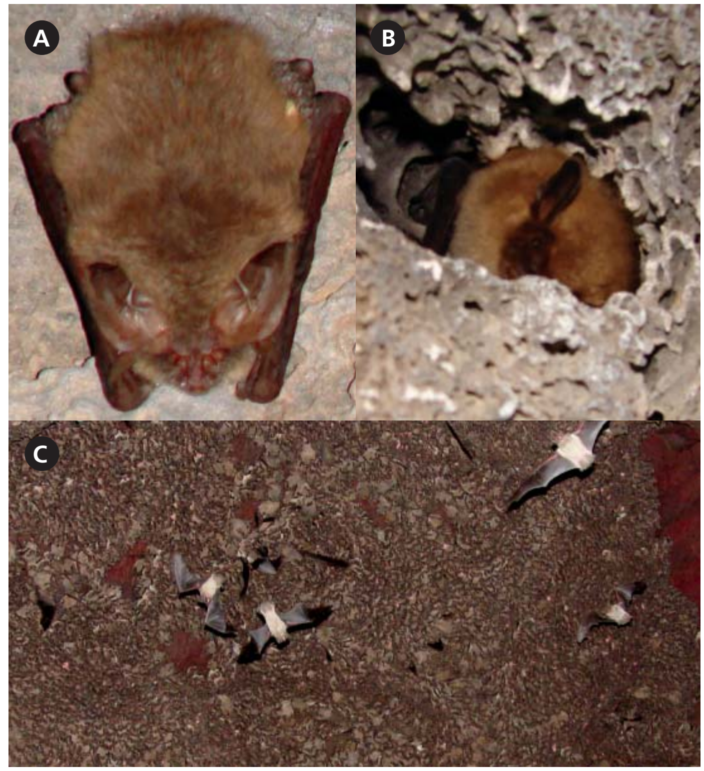

Figure 7. (A) Hibernating Townsend's big-eared bat and (B) big brown bat aroused from torpor at ELMA-054. (C) Late-season maternity colony of Mexican free-tailed bats within ELMA-062. Note that the "rough" surface in this panel is actually tightly clustered roosting bats. For scale, the average wingspan of Mexican free-tailed bats is 301 mm (12 in) (refer to Wilkins 1989).

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a stick and had several lacerations along the length of its body; I suggest a park visitor probably killed this animal. Because I do not know whether the snake was killed in the cave or it was brought into the cave postmortem, its use of the cave is "unknown." Finally, a barn owl (*Tyto alba*; eisodophile) was spooked as my team entered ELMA-262. This owl was roosting near the entrance and then flew to a skylight where it exited the cave.

Conservation and management

This work resulted in the identification of seven new species of cave-dwelling arthropods (including two potential troglobites), range expansions of two parasitoidal wasps, and two caves containing significant root curtains hanging from the ceiling. The presence of root curtains and moss gardens has been shown to be an important driver of high arthropod richness at El Malpais lava tube caves. For bats, I confirmed continued use of one hibernaculum cave and two significant bat maternity roosts. Although all of these caves will require further study, these findings have been useful in highlighting future management directions and research needs.

Arthropods

Four of the new species reported here are dependent on caves for most or all of their life cycle. The potentially new troglomorphic spider (*Theridion* n.sp.?) and the planthopper (Fulgoroidea n.sp.?) are likely to be restricted to the cave environment, while the cricket (*Ceuthophilus* cf *apache* n.sp.) and beetle (*Rhadine* n.sp., *perlevis* species-group) are trogloxenes. Unfortunately, only one specimen of *Theridion* n.sp.? was detected and collected; additional specimens will be required to describe this animal and determine whether it is indeed troglomorphic. In the two caves with root curtains, I identified at least one potential troglobite, a planthopper (Fulgoroidea n.sp.?). Unfortunately, all specimens collected were nymphs, and adults are required to confirm both cave adaptation and whether or not it is a new species. The remaining three newly discovered species likely occur in surface habitats as well as caves. The two new springtail species (*Drepanura* n.sp. and *Pogonognathellus* n.sp.) are edaphic

(soil-dwelling) organisms. *Histiostoma* n.sp. is a very small mite (600–900 µm [0.6–0.9 mm] in length) and is found in association with other insects. Because the deutonymph (early life stage of mites) hitchhikes on larger-bodied insects for dispersal between habitats, this mite may have been transported into the cave by another animal. Both springtails and mites will require further study to determine their affinities for caves and the ecological roles they play in the cave environment.

To address questions concerning population dynamics and distribution patterns of these new arthropod species, additional surveys at caves known or likely to support these animals will be required. This information will be necessary to develop resource management plans to best protect these species and their habitats. All of these new species should be considered important finds because they expand our knowledge of the natural history of El Malpais National Monument and, by extension, the state of New Mexico.

Bats

ELMA-054 supports the largest known hibernaculum of Townsend's big-eared bats on the monument, while ELMA-110 supports the largest known maternity roost of this species. Wynne (2006) counted 100 Townsend's big-eared bats hibernating in the deepest section of ELMA-054. ELMA-110 supports a maternity roost of Townsend's big-eared bats, estimated at 50 individuals in 2006 (Wynne, unpublished data). ELMA-110 has been closed to park visitors for several years while bats are in residence. As a result of this study and the 2006 site visit, ELMA-054 is now closed during the hibernation period (October through mid-April).

Based on our knowledge of Townsend's big-eared bats in other areas, I suggest the same population uses both roosts. In Oklahoma, movements of these bats between maternity roosts and hibernacula averaged 11.6 km (7.2 mi) (range 3.1 to 39.7 km [1.9–24.7 mi], n = 3 individuals; Humphrey and Kunz 1976). Dobkin et al. (1995) documented Townsend's big-eared bats traveling distances ranging from 5 to 24 km (3–15 mi) from summer roost to foraging sites in Oregon. Additionally, Pierson et al. (1999) suggested that this species was in decline throughout its range. The straight-line distance from ELMA-110 to ELMA-054 is 10.5 km (6.5 mi).

Given that this species is likely to be the most affected by white-nose syndrome on the monument, knowledge of this bat's habits, movements, and roost locations will enhance its management and protection. I recommend conducting a radio tagging and telemetry study of Townsend's big-eared bats and their use of these two roosts. For such a project, radio tagging of bats should occur late in the maternity season (late August to early September). This project would enable monument personnel to (1) establish baseline estimates of population size and structure to begin monitoring this species and its two known roosts, (2) determine if the same population is using both ELMA-110 and ELMA-054, (3) potentially identify additional Townsend's big-eared bat roosts by tracking bat movements with telemetry, and (4) make informed decisions regarding potential cave closures and protection of this species.

Scientists and managers know little about the winter habitat requirements of year-round bat residents at El Malpais. Thus, more surveys are needed, particularly winter bat inventories, to identify additional hibernacula. I recommend annual to biennial monitoring of ELMA-054, as well as newly identified hibernacula and long-term microclimatic monitoring in caves supporting hibernating bats. In light of the westward advance of white-nose syndrome and global climate change, this information may be useful in guiding management decisions to protect bat populations in the future. Additionally, information gathered by such an endeavor may be informative for developing similar monitoring strategies for other management units of the National Park System in the southwestern United States.

Deep zones and unique habitats

All deep zone environments that support or have the potential to support cave-adapted animals should be considered high-priority sites for conservation and management. Deep zones are characterized where environmental conditions (e.g., complete darkness, temperature, relative humidity, moisture, airflow) remain relatively stable over time (refer to Howarth 1980 and 1982). When nutrients are added to this equation (via root curtains protruding from the ceiling, bat guano, or dissolved organic material percolating through rock), these areas should be intensively sampled for troglomorphic arthropods. For example, Howarth et al. (2007) stressed the importance of roots in caves for conserving troglomorphic arthropods in Hawaiian lava tubes.

Three caves on the monument meet these criteria. ELMA-315 and ELMA-303 contain deep zones with extensive root curtains hanging from the ceiling. During the arthropod sampling period, these caves were among the warmest on the monument (ELMA-315: mean temperature 12.4°C [54.3°F], standard deviation 0.5°C [0.9°F]; ELMA-303: mean temperature 11.9°C [53.4°F], standard deviation 0.7°C [1.3°F]). I know of no other caves in the region that support this microhabitat type. Additionally, ELMA-110 has the most extensive deep zone microhabitat known on the monument. At the terminus of this cave, water percolates through fissures into the cave chamber. I recommend conducting additional surveys in all of these caves using a bait sampling and direct intuitive search sample design (*sensu* Wynne 2010 and Wynne et al. 2012). These inventories, conducted during the most produc-

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tive times of year (i.e., spring and summer), would likely result in the detection of additional troglomorphic arthropods.

Because cave-adapted animals are cryptic, they are often difficult to detect and researchers must conduct numerous site visits to obtain even a baseline knowledge of community composition. For example, Krejca and Weckerly (2007) reported that 10 to 22 site visits were required to detect three endangered arthropods known to occur in Texas caves. Although it is not directly applicable to terrestrial cave-dwelling invertebrates, Culver et al. (2004) reported that Sket (1981) discovered a new stygobite (an aquatic cave-adapted animal belonging to a new genus) after more than 100 collecting trips to a cave in Slovenia. During this study, I identified two potential troglobites and detected only one of five troglobites originally identified by Northup and Welbourn (1997). This not only underscores the inefficiency in our abilities to effectively detect cave-adapted animals but also emphasizes the need for additional inventory work in deep zone microhabitats.

ELMA-054 is home to a troglomorphic bristletail (order Diplura: family Campodeidae). It has been detected on the mud floors of a small chamber at the terminus of this cave. This animal may prove to be a narrow-range endemic (occurring in this cave and nowhere else on the planet). To best protect this animal and its habitat, in 2013 monument personnel permanently closed the deepest section of ELMA-054 to all recreational use.

Another important and highly sensitive microhabitat is moss gardens. These areas have been identified as relict habitats of the last glacial maximum (approximately 20,000 years ago) and support species now restricted to this environment at both El Malpais (Northup and Welbourn 1997) and in Oregon (Benedict 1979). Species richness for both ELMA-012 and ELMA-008 was driven by the large number of species detected within moss gardens at cave entrances and beneath skylights. Roughly 25% of the arthropods detected during the Northup and Welbourn (1997) study were found within moss gardens.

Because moss gardens are considered relict habitats and have been shown to support large numbers of species, this microhabitat should be afforded the highest level of protection. In 2013 ELMA-012 was closed to recreational use. Moss gardens within ELMA-008 have been roped off and signage has been posted indicating the fragility of these habitats. Based on my observations of both caves since 2005, this approach seems to be deterring foot traffic in these areas. However, some of the posts supporting the rope have fallen. More frequent maintenance of the posts and ropes, and adding more signage in ELMA-008, are relatively inexpensive measures that may serve to better protect these important microhabitats. Should ELMA-012 reopen in the future, I recommend using the same management and maintenance approach described for ELMA-008.

I did not detect any arthropods in ELMA-029 because I did not have an opportunity to sample the moss gardens in the cave entrance (as Northup and Welbourn [1997] did during their work). I observed no signs of recent human use or visitation when I was there in 2007. Given its remote location (approximately 1.6 km [1 mi] from an unmaintained dirt road), this cave and its moss gardens are likely well protected.

ELMA-029 also contains the most significant ice deposit on the monument, with a meters-thick ice sheet extending from near the entrance to the back of the cave. Cave interior and deep zone temperatures fluctuated from near to below freezing (mean temperature = 0.141°C [32.25 °F], standard deviation = 1.21°C [2.18°F]) during the arthropod sampling period. Although this cave is not suitable habitat for most arthropod species, it is possible that ice crawlers (order Notoptera: family Grylloblattidae) occur there and in other ice caves on private lands adjacent to the monument. These animals are known to occur in caves at both Oregon Caves and Lava Beds National Monuments (Jarvis and Whiting 2006) and would be a significant discovery at El Malpais. If ice crawlers exist within this cave, these animals would likely be relict species of the last glacial maximum. I suggest surveys for ice crawlers be conducted at ELMA-029, as well as at other ice caves in the El Malpais region.

Future directions

The information presented here provides a solid foundation on which to continue building knowledge of cave natural resources on the national monument, and has already proven useful in managing these resources. Additional studies targeting the use of lava tubes by cave-roosting bats, the distributional extent of known troglomorphic arthropods in caves or groups of caves, additional sampling for several of the new species discussed here, and further study of cave deep zones, root curtains, moss gardens, and cave ice sheets will be required to obtain the data necessary for optimal conservation and management of lava tube cave biological resources at El Malpais National Monument. My hope is that some of the protocols presented here and the recommendations made will be useful in the development and implementation of a monitoring framework that may be used to gauge the response of sensitive cave-dwelling animals to recreational use, invasive species, global climate change, and white-nose syndrome.

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APPENDIX A IS AVAILABLE ONLINE AT HTTP://WWW.NATURE.NPS.GOV/PARKSCIENCE/ARCHIVE/PDF/ARTICLEPDFS/PARKSCIENCE30(1)SUMMER2013_A1–A12_WYNNE_3653.PDF

PS

Research Report

APPENDIX A

Annotated list of cave-dwelling taxa

By J. Judson Wynne

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Editor's note: The following is an online-only supplement to the research report "Inventory, conservation, and management of lava tube caves at El Malpais National Monument, New Mexico," by J. Judson Wynne. It can be cited as Wynne, J. J. 2013. Appendix A: Annotated list of cave-dwelling taxa. [Online supplement.] Park Science 30(1)Appendix A:1–12. Available online at http://www.nature.nps.gov/ParkScience/archive/PDF/Article_PDFs/ParkScience30(1)Summer2013_A1-A12_Wynne_3653.pdf.

Author's notes: In cases where members of a given morphospecies were detected only in entrances and twilight zones, I erred cautiously and referred to them as "eisodophiles." In cases where both the location of the detection and known information concerning the morphospecies supported the likelihood of an animal being "troglophillic," but I was still uncertain, I categorized the animal as a "questionable troglophile." Additionally, when a morphospecies was found only in the deep zone of a cave (or several individuals of a morphospecies occurred only within the deep zone) but troglomorphic characters were lacking, I also referred to it as "questionable troglophile."

THERE WERE SEVERAL CASES WHERE INDIVIDUALS EVADED CAPTURE BUT WERE BELIEVED TO represent a distinct arthropod morphospecies for a given cave. Because this information is of limited value in this article, arthropod morphospecies groups for which specimens are lacking were not included. However, this information has been integrated into a larger El Malpais morphospecies database and will be analyzed and the results reported in additional publications.

For arthropod groups actively being studied, I either sent specimens or high-resolution images of specimens to taxonomic specialists for identification or verification of my identifications. These experts include Rolf Aalbu, Department of Entomology, California Academy of Sciences, San Francisco, California (Coleoptera: Tenebrionidae); R. Thomas Allen, The Academy of Natural Sciences of Drexel University, Philadelphia, Pennsylvania (Diplura); Max Barclay, Natural History Museum, London (Coleoptera), and Thomas Barr (deceased), formerly with Department of Biology, University of Kentucky, Lexington, Kentucky (Coleoptera: Carabidae); Ernest Bernard, Department of Entomology, The University of Tennessee, Knoxville (Collembola); Jostein Kjaerandsen, Museum of Zoology, Lund University, Lund, Sweden (Diptera: Mycetophilidae); Sarah Oliveira, Department of Biology, University of São Paulo, Brazil (Diptera: Mycetophilidae); Theodore Cohn (deceased), formerly with Department of Zoology, San Diego State University, California (Orthoptera: Rhamphidophoridae); Lynn Kimsey, Department of Entomology, University of California, Davis (Hymenoptera: Tiphiinae); Robert Johnson, School of Life Sciences, Arizona State University, Tempe (Formicidae); Edward Mockford, Department of Biology, University of Illinois, Normal (Psocoptera); Glené Mynhardt, Department of Evolution, Ecology, and Organismal Biology, The Ohio State University, Columbus (Coleoptera: Ptinidae); Barry O'Connor, Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor (Acari); Stewart Peck, Department of Biology, Carleton University, Ottawa, Ontario, Canada (Coleoptera: Leiodidae); Pierre Paquin, Cave and Endangered Invertebrate Research, SWCA Environmental Consultants, Austin, Texas (Araneae); William Shear, Department of Biology, Hampden-Sydney College, Hampden Sydney, Virginia (Myriapods and Opiliones); and Harald Schillhammer, Department of Entomology, Naturhistorische Museum, Vienna, Austria (Coleoptera: Staphylinidae). For all other specimens, Colorado Plateau Museum of Arthropod Biodiversity staff and I identified the specimens to the lowest taxonomic level possible using available taxonomic keys.

"Det." following each species or morphospecies designation is the abbreviation for the Latin *dēterminēvit* or "determined by."

Phylum Arthropoda

Class Arachnida

Order Araneae

Family Araneidae

***Metellina mimetoides* Chamberlin & Ivie, 1941**. Det. P. Paquin. Eisodophile.

One adult female was collected via timed search in the twilight zone of ELMA-262. Additionally, one juvenile specimen that may represent this species was collected via timed search at the entrance of ELMA-262.

Family Linyphiidae

Note: Numerous troglobitic and troglophillic forms of this family are known globally (e.g., Ruzicka 1998; Deltshev and Curcic 2002; Miller 2005).

Linyphiidae sp. Det. P. Paquin. Eisodophile.

One juvenile specimen was collected opportunistically near the entrance of ELMA-262. Another juvenile was collected via timed search in the twilight zone of ELMA-303.

***Lepthyphantes* sp**. Det. P. Paquin. Eisodophile.

Two female specimens were collected by timed searches at the entrance of ELMA-012; one female specimen was collected using direct intuitive searches in the moss gardens of ELMA-008.

***Porrhomma* sp. 1**. Det. P. Paquin. Troglophile?

One female specimen was collected using direct intuitive searches within root curtains in the deep zone of ELMA-315.

***Porrhomma* sp. 2**. Det. P. Paquin. Troglophile?

One female specimen was collected using direct intuitive searches within root curtains in the deep zone of ELMA-303. P. Paquin (personal communication, e-mail, 23 March 2007) suggests it differs from *Porrhomma* sp. 1.

Family Liocranidae

Liocranidae sp. Det. P. Paquin. Troglophile?

One juvenile specimen was collected via timed search in the deep zone of ELMA-012.

Family Nesticidae

Note: Nesticidae has an impressive cave fauna globally (Hedin 1997; Cokendolpher and Reddell 2001; Snowman et al. 2010).

Nesticidae sp. Det. P. Paquin. Eisodophile.

One juvenile specimen was collected opportunistically from the twilight zone of ELMA-012.

***Eidmanella pallida* (Emerton, 1875)**. Det. P. Paquin. Troglophile.

Three females were collected using direct intuitive searches within root curtains in the deep zone of ELMA-315. Two juvenile specimens (identified as Nesticidae sp.) were collected using direct intuitive searches within root curtains in the deep zone of this cave. While unconfirmed, these juveniles may also be *Eidmanella pallida*.

Note: Reddell and Cokendolpher (2004) consider this species a troglophile in Texas caves.

Family Pholcidae

Note: Both troglophillic and troglobitic forms of this family are known globally (e.g., Gertsch and Peck 1992; Deeleman-Reinhold 1993; Chen et al. 2011; Ferreira et al. 2011).

***Psilochorus* sp. 1**. Det. P. Paquin. Troglophile?

One male and two females were collected using direct intuitive searches within root curtains in the deep zone of ELMA-303. Three males were collected via timed searches (n = 2) and pitfall trapping (n = 1) at the entrance and beneath the skylights of ELMA-008. One female specimen was identified via timed search in the twilight zone, directly below the entrance of ELMA-315. Two males were collected by timed searches in both the entrance and deep zone of ELMA-012, and two individuals (1 male, 1 female) were collected via timed search from the entrance in Hummingbird Cave.

***Psilochorus* sp. 2**. Det. P. Paquin. Troglophile?

Two individuals were collected opportunistically in the deep zone near the bat maternity roost in ELMA-062. One adult female specimen was designated as a different species from *Psilochorus* sp. 1 (P. Paquin, personal communication, e-mail, 4 December 2009). Additionally, one juvenile specimen identified as *Psilochorus* was collected from the same cave. I suggest it is probably the same morphospecies because an adult female was identified in the same area as the juvenile specimen.

Family Theridiidae

***Achaearanea porteri* (Banks, 1896)**. Det. P. Paquin. Troglophile.

Two females were collected using timed searches, one near the entrance and the other in the twilight zone of ELMA-303. Three females were collected via direct intuitive searching (n = 2) in root curtains and with timed searches (n = 1) in the deep zone of ELMA-315.

Note: Cokendolpher and Reddell (2001) consider this species a troglophile in Texas caves.

***Nesticodes rufipes* (Lucas, 1846)**. Det. P. Paquin. Troglophile.

Three adult females were collected using direct intuitive searches in root curtains from the deep zone of ELMA-315.

Note: Because all were located within the same location and none had characters suggestive of troglomorphism, I consider this spider a troglophile. Additionally, theridiid spiders have been widely documented globally as being both troglophiles and troglobites (e.g., Ferreira and Martins 1998; Ruzicka 1998; Dippenaar-Schoeman and Myburgh 2009).

***Steatoda* sp**. Det. P. Paquin. Unknown.

One juvenile specimen was collected from a pitfall trap within the twilight zone of ELMA-062.

***Theridion* n.sp**.? Det. P. Paquin. Troglobite?

One adult female was collected via timed search in the twilight zone of ELMA-262. P. Paquin (personal communication, e-mail, 23 March 2007) suggests this may be a new species, and potentially has cave-adapted characteristics.

Order Opiliones

Family Sclerosomatidae

***Leiobunum townsendii* Weed, 1893**. Det. W. Shear. Trogloxene.

This harvestman (n = 13) was identified from ELMA-012, ELMA-062, ELMA-008, ELMA-262, ELMA-303, ELMA-315, and Hummingbird Cave. It was collected via direct intuitive search in the moss gardens of ELMA-008 and ELMA-012 and in root curtains in the deep zone of both ELMA-303 and ELMA-315. It was collected both opportunistically and via timed search in the entrances and twilight zones of ELMA-062 and Hummingbird Cave. W. Shear (personal communication, e-mail, 12 April 2009) suggests this group in western North America requires major revision. It is possible multiple species exist across the southwestern United States, or greater North America. However, until it is revised, the accepted name provided here will be used.

Subclass Acari

Order Sarcoptiformes

Family Histiostomatidae

***Histiostoma* n.sp**. Det. B. O'Connor. Troglophile?

Two deutonymphs were collected during timed searches in the deep zone of ELMA-315. B. O'Connor indicates this is an undescribed species. This animal is similar to *H. pierrestrinati* described from Carlsbad Cavern (B. O'Connor, personal communication, e-mail, 3 August 2012).

Order Trombidiformes

Family Bdellidae

Bdellidae sp. Det. B. O'Connor. Troglophile?

One specimen was collected by direct intuitive searches in the deep zone of ELMA-303. The palpi were damaged during collection, so lower-level taxonomic identification was not possible. B. O'Connor (personal communication, e-mail, 3 August 2012) indicates this family contains predators of soil, leaf litter, and littoral zones.

Family Erythraeidae

***Erythraeus* sp**.? Det. B. O'Connor. Eisodophile.

Five specimens were captured via pitfall trapping from the twilight zone of ELMA-008. B. O'Connor (personal communication, e-mail, 3 August 2012) indicates this genus is known from the Southwest, but no species are described. Additional analysis will be required to identify these specimens to a lower taxonomic level.

Family Rhagiididae

Rhagiididae sp. Det. B. O'Connor. Troglophile?

One specimen was collected by direct intuitive searches in the dark zone of ELMA-012. The specimen was damaged and could not be identified beyond family level.

Family Smarididae

***Phanolophus* sp**. Det. B. O'Connor. Unknown.

One specimen was collected via pitfall trapping at the entrance of ELMA-012. This family of predatory mites has not been studied in North America (B. O'Connor, personal communication, e-mail, 3 August 2012).

Subphylum Myriapoda

Class Chilopoda

Order Lithobiomorpha

Family Gosibiidae

Gosibiidae sp. Det. B. Shear. Troglophile?

One specimen was collected using direct intuitive searches from root curtains in the deep zone of ELMA-303. Additional specimens will be required to identify this centipede beyond the family level (W. Shear, personal communication, e-mail, 9 October 2009).

Class Diplopoda

Order Chordeumatida

Family Contylidae

***Austrotyla* sp**.? Det. W. Shear. Eisodophile.

This specimen (n = 1), identified to genus level by W. Shear, was collected via direct intuitive search from the moss gardens of ELMA-008. Additional specimens will be required to identify this animal to a lower taxonomic level.

***Austrotyla* cf *coloradensis* (Chamberlin, 1910)**. Det. W. Shear. Troglophile?

One specimen was collected using direct intuitive searches from root curtains in the deep zone of ELMA-315. This is a tentative species designation because of a lack of material. Additional specimens will be required to confirm this species designation.

Class Entognatha

Order Collembola

Note: The two new collembolan species will be included in a paper describing several new cave-dwelling Collembola species from the southwestern United States.

Family Entomobryidae

***Drepanura* n.sp**. Det. E. Bernard. Troglophile?

One specimen was collecting using pitfall trapping near the entrance of ELMA-008. E. Bernard (personal communication, e-mail, 15 July 2010) indicates this specimen represents a new species.

***Entomobrya guthriei* Mills, 1931**. Det. E. Bernard. Troglophile?

Five specimens were collected via pitfall trapping from the twilight zone to the deep cave zone of ELMA-110.

Entomobrya zona? Christiansen & Bellinger, 1980. Det. E. Bernard. Troglophile?

All specimens were collected in the entrances and twilight zones of ELMA-012 (n = 28) and ELMA-008 (n = 4). Seven specimens were collected using direct intuitive searches from moss gardens beneath the skylights of ELMA-012. All of the remaining specimens were captured using pitfall trapping. They likely represent *E. zona*. E. Bernard (personal communication, e-mail, 15 July 2010) made this tentative species designation, but indicated the specimens are not a "sure fit" for this species.

Family Tomoceridae

***Pogonognathellus* n.sp**. Det. E. Bernard. Eisodophile.

All specimens were collected via direct intuitive searches from the moss gardens of ELMA-008 (n = 10) and opportunistic collecting of ELMA-012 (n = 2). E. Bernard (personal communication, e-mail, 15 July 2010) suggests these specimens represent a new species.

Order Diplura

Family Campodeidae

Campodeidae n.sp. Det. J. Wynne and T. Allen. Troglobite.

This animal was first reported by Northup and Welbourn (1997). Five specimens were collected using direct intuitive searches from the "mud room" at the terminus of ELMA-054. Dipluran taxonomist Dr. Thomas Allen has these specimens and has confirmed this as a new species (personal communication, e-mail, 5 May 2013). I will be working with him to describe this new species.

Class Insecta

Order Coleoptera

Family Carabidae

***Rhadine* n.sp. *perlevis* species-group**. Det. T. Barr. Trogloxene.

These carabid beetles (n = 25) were identified primarily by pitfall trapping (but also with opportunistic collecting and timed searches) from ELMA-062, ELMA-110, ELMA-262, ELMA-303, and ELMA-315. This animal was observed from the twilight to deep zones of most caves. These specimens were initially sent to Dr. Thomas Barr for identification. T. Barr (personal communication, e-mail, 12 June 2009) suggested the specimens represent a new species and they belong to the *perlevis* species-group of *Rhadine*. Dr. Barr passed away in April 2011. The specimens are now at the Carnegie Museum of Natural History in Pittsburgh, Pennsylvania, and are awaiting formal description. Dr. Kipling Will, Essig Museum of Entomology, University of California, Berkeley, is coordinating this effort.

Family Cryptophagidae

Cryptophagidae sp. Det. M. Barclay. Eisodophile.

One specimen was collected via pitfall trapping from the entrance of ELMA-062. Additional work will be required to identify this specimen to a lower taxonomic level.

Family Leiodidae

***Dissochaetus arizonensis* Hatch, 1933.** Det. S. Peck. Accidental.

This leiodid beetle was collected from cave entrances of ELMA-012 (n = 1) and ELMA-062 (n = 1), while specimens from ELMA-315 (n = 2) were detected in the cave deep zone; all were captured using baited pitfall traps.

Note: S. Peck (personal communication, e-mail, 28 February 2013) suggests this species is an accidental because there are no data to suggest it is a regular cave dweller or that it reproduces in caves.

Family Melyridae

***Listrus* sp**. Det. M. Barclay. Eisodophile.

This coleopteran was captured via pitfall trapping (n = 1) in the twilight zone of ELMA-262. This specimen will require further study.

Family Ptinidae

***Niptus ventriculus* LeConte, 1859.** Det. G. Mynhardt. Troglophile.

Five spider beetle specimens were collected via pitfall trapping in ELMA-008 (n = 1), ELMA-012 (n = 2), and ELMA-262 (n = 1) and by opportunistic collecting in ELMA-062 (n = 1). Four specimens were collected in the cave entrances, while one specimen was collected in the twilight zone.

Note: Spilman (1968) documented this species in packrat middens, while Aalbu (2005) indicated

larvae and potentially adults feed on the scat of packrats. Given that habitat exists for these spider beetles and that they complete a portion of their life cycle underground, I consider this animal a troglophile.

Family Staphylinidae

Staphylinidae sp. Det. J. Wynne. Eisodophile.

One individual was collected from the entrance of ELMA-012 during time searches. Additional work will be required to identify this specimen to a lower taxonomic level.

Subfamily Tachyporinae

***Sepedophilus* sp**. Det. H. Schillhammer. Eisodophile.

Three individuals were collected from the twilight zone of ELMA-062 (n = 2) and entrance of ELMA-315 (n = 1). Each specimen was detected using a different technique from the others: opportunistic collecting, timed searches, and pitfall traps. H. Schillhammer (personal communication, e-mail, 19 April 2013) suggests this genus is generally not associated with caves.

Family Tenebrionidae

***Neobaphion planipennis* (LeConte, 1866).** Det. R. Aalbu. Trogloxene.

Four individuals were collected opportunistically and via timed search from ELMA-062 (n = 3) and using direct intuitive searches in ELMA-303 (n = 1). In ELMA-062 this species was observed in the dark zone and beneath a skylight entrance; the individual in ELMA-303 was collected from the deep zone.

Note: Aalbu et al. (2012) consider this species an occasional trogloxene in ELMA-062.

Order Diptera

Family Culicidae

Culicidae sp. Det. J. Wynne. Trogloxene.

One culicid fly was collected opportunistically from the entrance of ELMA-012 and one via timed search in the deep zone of ELMA-315. Additional work will be required to identify this specimen to a lower taxonomic level.

Note: Reeves et al. (2000) and Makiya and Taguchi (1982) identified mosquitoes as trogloxenes.

Family Mycetophilidae

***Mycetophila* sp**. Det. J. Kjaerandsen and S. Oliveira. Trogloxene?

One specimen was collected using direct intuitive searches from the root curtains in the deep zone of ELMA-303. Additional work will be required to identify this specimen to a lower taxonomic level.

Note: Peck (1981) considered a morphospecies of this genus and five morphospecies of this family to be trogloxenes from two caves (>2,134 m [7,000 ft] elevation) in the Uinta Mountains, Utah. Additionally, from caves in Grand Canyon National Park, Peck (1980) considered a morphospecies of this genus to be a trogloxene.

Family Phoridae

Phoridae sp. Det. J. Wynne. Eisodophile.

Eight specimens were collected from pitfall traps at the entrance of ELMA-062 (n = 7) and in the twilight zone of ELMA-008 (n = 1). One individual was collected using direct intuitive searches in the moss gardens beneath skylights of ELMA-012. Additional work will be required to identify

these specimens to a lower taxonomic level.

Family Sciaridae

Sciaridae sp. Det. J. Wynne. Eisodophile.

Twenty-one specimens were collected via opportunistic collecting, pitfall trapping, and timed searches from the entrance to the middle of ELMA-062; one specimen was collected using direct intuitive searches from the moss gardens beneath a skylight of ELMA-008; and three specimens were collected opportunistically from the entrance of ELMA-061. Additional work will be required to identify these specimens to a lower taxonomic level.

Order Hemiptera

Infraorder Fulgoromorpha

Superfamily Fulgoroidea

Fulgoroidea n.sp.? Det. J. Wynne. Troglobite?

Nymphal-stage planthoppers were collected using direct intuitive searches in root curtains from the deep zones of ELMA-303 and ELMA-315. Adults will be required to confirm troglomorphism, identify to a lower taxonomic level, and determine new species status.

Order Hymenoptera

Family Formicidae

***Liometopum* sp**. Det. R. Johnson. Eisodophile.

One undetermined *Liometopum* specimen was collected using direct intuitive searches in the moss gardens of ELMA-008.

***Pheidole* sp**. Det. R. Johnson. Eisodophile.

Two minor workers (R. Johnson, personal communication, e-mail, 10 December 2010) were collected via pitfall trapping near the entrance and at close proximity to the moss gardens of ELMA-008.

Family Tiphiidae

Note: All specimens of both tiphiid wasp species were found in a torpor beneath rocks; given the time of season, I suggest these individuals were in the early stages of hibernation and were likely using moss gardens as winter habitat.

***Tiphia andersoni* Allen, 1971**. Det. L. Kimsey. Eisodophile.

One female specimen was collected using direct intuitive searches in moss gardens (beneath large skylights) of both ELMA-012 and ELMA-008. Historically, this wasp is known to occur in central Mexico as well as southeastern and north-central Arizona (Allen 1971). This animal was not known to occur in New Mexico and thus represents a range expansion.

***Tiphia nona* Allen, 1965.** Det. L. Kimsey. Eisodophile.

One female specimen was collected using direct intuitive searches in the moss gardens of ELMA-008. Previously it was known from central Mexico, southeastern Arizona to the southern extent of the Mogollon Rim, and one locality in southwestern Kansas (Allen 1971). This animal was not known to occur in New Mexico and thus represents a range expansion.

Order Lepidoptera

Note: None of the larval specimens were reared in the lab and I was unable to locate a key for Lepidoptera larvae. Thus, all lepidopteran specimens have been sorted into operational taxonomic units, and further identifications were not possible before this article was published. This level of identification is acceptable for community-level as well as other analyses, which will be the subject of additional scientific publications.

Lepidoptera sp. 1. Det. J. Wynne. Troglophile?
Three larval specimens were collected with pitfall traps (n = 2) and via direct intuitive searches (n = 1) from the root curtains within the deep zone of ELMA-315.

Lepidoptera sp. 2. Det. J. Wynne. Troglophile?
Four larval specimens were collected using direct intuitive searches of the root curtains within the deep zone of ELMA-315 (n = 3) and ELMA-303 (n = 1).

Lepidoptera sp. 3. Det. J. Wynne. Troglophile?
One larval specimen was collected using direct intuitive searches of the root curtains within the deep zone of ELMA-315.

Lepidoptera sp. 4. Det. J. Wynne. Troglophile?
One larval specimen was collected using direct intuitive searches of the root curtains within the deep zone of ELMA-315.

Lepidoptera sp. 5. Det. J. Wynne. Troglophile?
One larval specimen was collected using direct intuitive searches of the root curtains within the deep zone of ELMA-303.

Lepidoptera sp. 6. Det. J. Wynne. Eisodophile.
One adult moth was collected during a timed search in the entrance of ELMA-262.

Lepidoptera sp. 7. Det. J. Wynne. Eisodophile.
One adult moth (different from Lepidoptera sp. 6) was collected during a timed search in the entrance of ELMA-012.

Family Tenididae

Tenididae sp. 1. Det. J. Wynne. Eisodophile.
One micro-lepidopteran was collected opportunistically in ELMA-262.

Tenididae sp. 2. Det. J. Wynne. Eisodophile.
One micro-lepidopteran (different from *Tenididae* sp. 1) was found in a pitfall trap in the twilight zone of ELMA-008.

Order Orthoptera

Family Rhaphidophoridae

***Ceuthophilus* sp**. Det. T. Cohn. Trogloxene.

One juvenile male was captured via pitfall trapping from the entrance of ELMA-010. Given this animal's immature state, it was not possible to identify it to a lower taxonomic level.

***Ceuthophilus* cf *apache* n.sp**. Det. T. Cohn. Trogloxene.

T. Cohn (personal communication, e-mail, 21 March 2011) indicated this was a new *Ceuthophilus* species, which is similar to *Ceuthophilus* cf *apache*. We collected one adult male and one adult female from ELMA-062, two adult males from ELMA-303, and one adult male from ELMA-315. This morphospecies was detected using opportunistic collecting, pitfall trapping and timed searches, and occurred from the entrances to each cave's dark/deep zone.

***Ceuthophilus* (*Geotettix*) *polingi* Hubbell, 1936**. Det. T. Cohn. Trogloxene.

T. Cohn and A. Swanson identified all specimens in this group. We collected two adult females and four adult males from ELMA-262, one adult male from Hummingbird Cave, one adult male from ELMA-012, one adult male from ELMA-054, one adult female and two adult males from ELMA-303, and two adult females from ELMA-315. This species was detected using opportunistic collecting, pitfall trapping, and timed searching, and occurred from the entrances to each cave's dark/deep zone. T. Cohn (personal communication, e-mail, 21 March 2011) suggested this animal was considered rare until recently; we now know it is widespread in its range, but probably restricted to caves and animal burrows.

Order Psocoptera

Family Psyllipsocidae

***Psyllipsocus ramburii* Selys Longchamps, 1872**. Det. E. Mockford. Troglophile.

This species was identified from ELMA-062 (n = 2), ELMA-262 (n = 1), and ELMA-315 (n = 6). With the exception of one individual collected opportunistically, all were detected in pitfall traps and from cave entrances to the dark/deep zones.

Note: This species is known to occur in caves globally (E. Mockford, e-mail, 1 February 2013). E. Mockford and I (unpublished data) recently confirmed this species on Easter Island, South Pacific Ocean, as well as from a cave on Grand Canyon–Parashant National Monument, Arizona.

Order Siphonaptera

Family Pulicidae

Pulicidae sp. Det. J. Wynne. Parasite.

Nine specimens were collected from ELMA-315. I found no evidence of recent rodent activity within either cave. However, the presence of fleas suggests recent vertebrate use. Additional work will be required to identify these specimens to a lower taxonomic level.

Phylum Chordata

Subphylum Vertebrata

Class Reptilia

Family Colubridae

***Pituophis catenifer* (Blainville, 1835)**. Det. J. Wynne. Unknown.

A gopher snake carcass was found in the twilight zone of ELMA-061. This individual had numerous lacerations along the length of its body. A park visitor probably killed the snake. Because I am uncertain whether the snake was killed in the cave or brought into the cave postmortem, its functional group status is "unknown."

Class Mammalia

Order Chiroptera

Family Vespertilionidae

***Corynorhinus townsendii* Cooper, 1837**. Det. J. Wynne. Trogloxene.

This bat has been documented hibernating in ELMA-054 since 2005 (Wynne 2006). A maternity roost exists at ELMA-110. This maternity roost has been documented both in the tunnel section prior to the main section of the cave and in the twilight zone of the cave's main section.

***Eptesicus fuscus* (Palisot de Beauvois, 1796)**. Det. J. Wynne. Trogloxene.

One torpid big brown bat was observed near the entrance of ELMA-054.

Family Molossidae

***Tadarida brasiliensis* (I. Geoffroy, 1824)**. Det. J. Wynne. Trogloxene.

A long-established maternity roost of Mexican free-tailed bats exists in ELMA-062. We observed bats in residence during the October 2007 work.

Order Rodentia

Family Muridae

***Neotoma* sp**. Det. J. Wynne. Trogloxene.

Evidence of *Neotoma* sp. was documented at both ELMA-062 and ELMA-061. Both *N. mexicana* and *N. albigula* have been confirmed on the monument (Bogan et al. 2007). Either or both of these species likely use these caves.

Order Carnivora

Unknown family, genus, and species. Xenosylle?

Small carnivore scat was observed at the entrance of ELMA-054 and in the twilight zone of ELMA-110. Because we neither observed small carnivores nor saw them hunting bats within either cave, "questionable xenosylle" is most appropriate.

Class Aves

Order Tytonidae

***Tyto alba* (Scopoli, 1769)**. Det. J. Wynne. Eisodophile.

A barn owl was spooked as the team entered ELMA-262. The animal was observed within the main entrance and flew deeper into the cave toward the next collapse pit entrance, where it exited the cave.

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