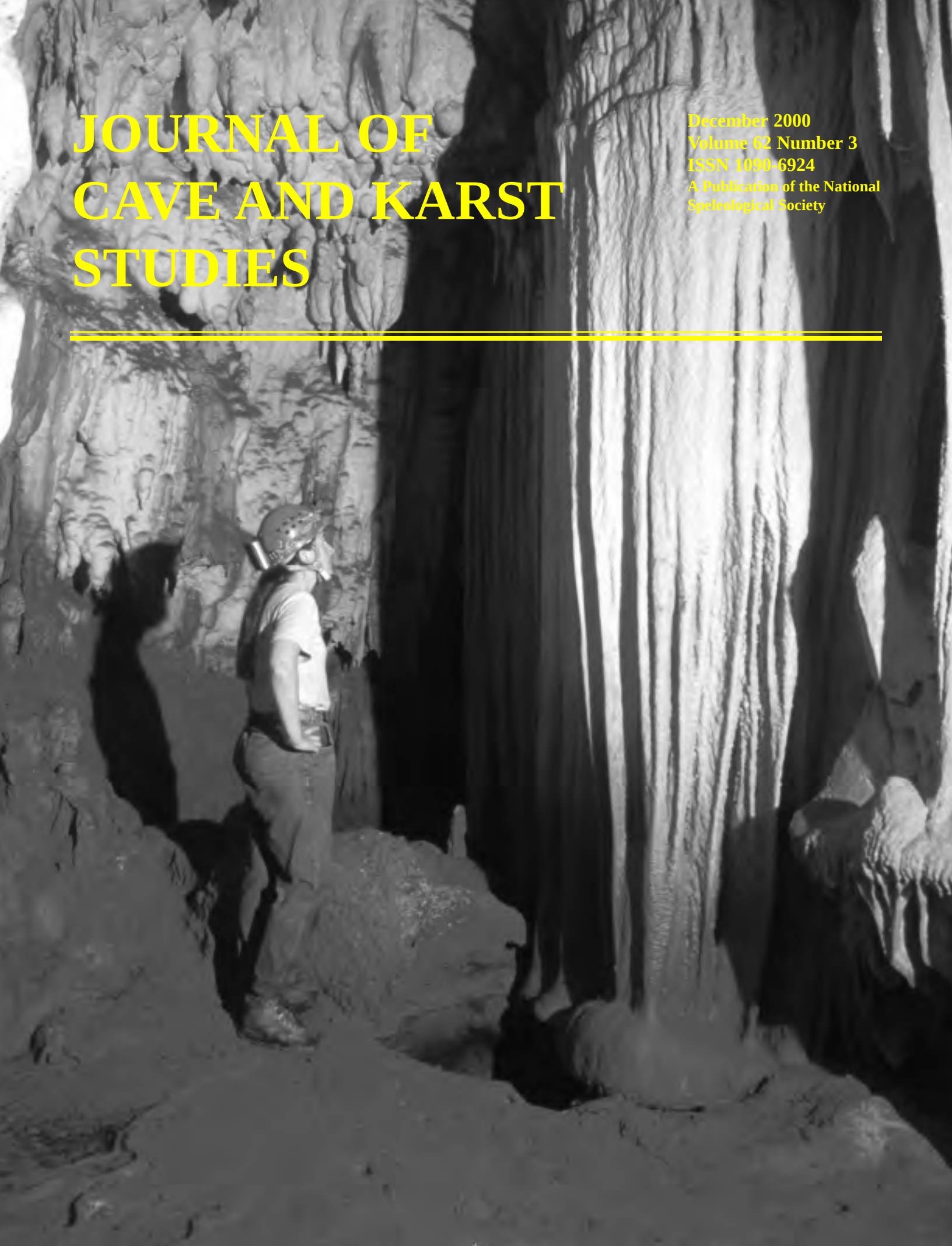


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EFFECT OF TRAIL USERS AT A MATERNITY ROOST OF RAFINESQUE'S BIG-EARED BATS

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While bat-roosting sites continue to be targets of vandalism, Hood Branch Rock Shelter in Natural Bridge State Park, Kentucky, provides habitat for Corynorhinus rafinesquii *(Rafinesque's big-eared bat). The shelter lies immediately adjacent to a hiking trail (Upper Loop Trail); therefore, the bats are potentially subject to disturbance by park visitors. This study monitored the behavior patterns of park visitors using the trail for potential disturbance effects at the shelter, and compared these data to population size and activity patterns of* C. rafinesquii *inhabiting the shelter from March to September 1998. Data indicate that a bypass trail directed many visitors away from the entrance to the shelter, but some visitors used the trail adjacent to the shelter and exhibited behavior potentially disruptive to the bats. The shelter was occupied by a maternity colony of* Corynorhinus rafinesquii *from late April to mid-July, a period in which access to the shelter was restricted due to debris and washouts along the trail from a severe storm in winter 1998. However, the shelter was abandoned by the bats within two weeks after the trail was cleared of debris. Although cause and effect cannot be directly inferred from collected data, the likelihood that the bats abandoned the shelter because of human intrusion is strong. The suitability of this shelter as a maternity roost of* C. rafinesquii *may be jeopardized by park visitors hiking the adjacent trail, suggesting closure of the Upper Loop Trail as the most viable option for protecting* C. rafinesquii *in Hood Branch Rock Shelter.*

Although conservation measures directed toward the preservation of bats should consider both roosting sites and above-ground foraging habitats (Pierson 1998), most efforts have addressed the protection of roosting sites. Roosting sites are situated in predictable habitats and are located in fixed positions in the landscape (Fenton 1997), and are important to the ecology of bats, providing habitat for feeding, resting, rearing of young, and hibernation (Kunz 1982). Conservation of bats through protection of roosting sites is confounded by a tendency in some species to switch roosts to meet their annual or seasonal habitat requirements, or to avoid predation and parasite infestation (Lewis 1995). Roost fidelity, however, is common in cave bats, with populations of many species entirely dependent on particular caves, mines, or rock shelters at various periods in their annual cycle (Kunz 1982; Lewis 1995).

Protection of roosting sites is an important strategy in the conservation of rare species of bats (Tuttle & Taylor 1994; Fenton 1997). The American Society of Mammalogists has established guidelines for researchers studying bats at roosting sites (ASM 1992), and set protocols exist for protecting bat roosting sites on federal lands (Lera & Fortune 1979). Many agencies that manage public lands in Kentucky have gated or fenced the entrance to roosting sites known to harbor populations of sensitive bat species (Lacki 1996). Regardless, bats occupying roosts where access is not restricted remain vulnerable to human disturbance.

The forms of human disturbance at bat roosting sites and their effects on bats are well documented (e.g., Tuttle 1979; Rabinowitz & Tuttle 1980; MacGregor 1991), and studies have examined the frequency of human intrusion into bat roosting sites (Tuttle 1979; Rabinowitz & Tuttle 1980). Limited information exists, however, on the behavior of humans at the entrance to bat roosts, and the need for such data has been expressed, especially for big-eared bats due to their extreme sensitivity to disturbance at maternity roosts (Bagley 1984).

Disturbance at summer maternity roosts can have a number of negative effects on bats including accidents to, and abandonment of, young bats, and increased energetic expenditures as the colony size declines (Herreid 1967; Gillette & Kimbrough 1970; Mohr 1972; Tuttle 1975; McCracken 1989). *Corynorhinus rafinesquii* (Rafinesque's big-eared bat) is a species that has been documented in need of protection in Kentucky (KSNPC 1996). This species forms summer maternity colonies in rock shelters at the northern range of its distribution (Hurst & Lacki 1999), requires a narrow range of temperature conditions inside roosting sites (Jones 1977), and is sensitive to human disturbance (Clark 1990). Further, although roost switching does occur in this species, data for populations in Kentucky show that some roosts are more important for reproduction than others (Hurst 1997; Hurst & Lacki 1999).

Corynorhinus rafinesquii has historically used a rock shelter in Natural Bridge State Park, Kentucky, as a summer roosting site. Measures taken to minimize disturbance by park visitors include the construction of an alternate trail to direct visitors away from the roost, and the placement of a 1-m tall fence and posted sign at the entrance to the roost. In this study, I evaluated the effectiveness of the alternate trail at keeping visitors away from the entrance to the roost, and monitored the response of bats to behavior of visitors.

STUDY AREA

Natural Bridge State Park is located in eastern Powell County, Kentucky, and is situated on the Cumberland Plateau

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province (McFarlan 1954). The physiography of the region includes various rock formations and a network of cliffs derived from Rockcastle sandstones and conglomerates (McGrain 1983). The outcropping rocks date back to the Pennsylvanian Period and include a layer of Beatyville shale underneath (McFarlan 1954). Below these rocks exists a layer of Mississippian Mammoth Cave limestone (McFarlan 1954). The existence of a sandstone surface layer, along with the limestone beds below, creates a geologic environment conducive to cave-dwelling bats. The surface rocks form highly weathered cliffs that contain numerous overhangs or shelters, while erosive forces forming caves have altered the limestone beneath (McGrain 1983). *Corynorhinus rafinesquii* use both limestone caves and sandstone rock shelters as roosting sites in Kentucky (Barbour & Davis 1969; 1974).

Hood Branch Rock Shelter is situated at the base of a southeast-facing cliff (~110°) at the headwaters of Upper Hood Branch, a tributary that drains the eastern half of the park. The shelter is a deep overhang comprised of two rooms with an entrance 22 m wide and 5.5 m high. A collapsed ceiling in the rear room created a domed surface that provides a dark zone during daytime in which *Corynorhinus rafinesquii* have historically formed maternity colonies (Hurst & Lacki 1997).

The vegetation of the park is representative of the mixed mesophytic forest type of the Central Hardwood Forest region (Preston 1989). The forest habitat in the immediate vicinity of the shelter is yellow-poplar (*Liriodendron tulipifera*), white oak (*Quercus alba*), chestnut oak (*Q. prinus*), sugar maple (*Acer saccharum*), and red maple (*A. rubrum*), with various pines (*Pinus* spp.) on top of the cliff. A thick shrub midstory is dominated by rhododendron (*Rhododendron maximum*), and the canopy closure in front of the shelter is ~ 75%.

Two hiking trails pass within < 0.1 km of the entrance to the shelter. Both trails form part of Hood Branch Trail which begins at a parking lot for the skylift in the park. Hood Branch Trail is 6.4 km in length and provides park visitors access to the Natural Bridge. Approximately 3 km from the trailhead, Hood Branch Trail forks into the Upper Loop and a shortcut trail called Reubens Cutoff. The Upper Loop passes immediately adjacent to the entrance of the shelter, with a 1-m tall wooden fence serving as a partition between the entrance to the shelter and the trail. The front room contains a posted sign that reads “Fragile Habitats - Stay on Trail.” Reubens Cutoff lies ~0.1 km from the entrance to the shelter. Reubens Cutoff was built in 1996 in an attempt to steer most park visitors off the Upper Loop and away from the shelter. Prior to this study, the extent to which this management prescription had influenced patterns of use by park visitors at the shelter was unclear.

METHODS

Sampling to assess patterns of use by park visitors was conducted semi-monthly on Saturdays and Sundays between 11 April and 20 September 1998. Weekend days were chosen for sampling because they reflect highest visitor use at the park (W. Francis, Natural Bridge State Park Naturalist, pers. comm.). On each day, the study sampled to qualify visitor use of the trails, and the intensity, duration and severity of visitor disturbance at, or inside, the shelter. Sampling sessions were 2 hours long between 1000 to 1330 hrs and again between 1400 to 1800 hrs EDT, respectively, and all days were either sunny or partly cloudy. Time observed, trail used, the size of the group, and the sex and estimated age as either adult or juvenile (≤ 16 years) was recorded for each group of trail visitors (defined as ≥ 1 person). For groups entering the shelter, records included the length of time spent inside and any noticeable activities that might have been disruptive to roosting bats. The hidden observer location permitted undetected monitoring activity on both the Upper Loop and Reubens Cutoff, while also keeping the entrance to the shelter in view. Binoculars with 7 x 35 magnification facilitated observation of park visitors.

A severe winter snowstorm in early 1998 resulted in numerous felled trees in the park and poor trail conditions at the start of sampling, requiring occasional off-trail travel. Park personnel cleared most debris from Reubens Cutoff by the start of surveys on 11 April, and passage to the entrance of the shelter along the Upper Loop between 28 June and 12 July 1998. Therefore, half of the sampling took place when visitor access to the shelter was difficult (i.e., limited access) and half after access to the shelter was improved (i.e., free access).

Sampling sessions by monitoring the shelter floor for evidence of visitor use supplemented the data. Following the cleanup of debris by 12 July along the Upper Loop, the soil on the surface of five large rocks on the floor of the outer room of the shelter was smoothed using a small brush. On the evenings of subsequent sampling dates, after the emergence of bats, evidence of foot traffic and any additional signs of visitor use were recorded and rock surfaces were resmoothed to allow the experiment to be repeated on subsequent sampling dates.

A comparison of levels of visitor use between trails and trail condition using 2-way analysis of variance (SAS Institute, Inc. 1992) examined variables including mean passage rate (# of groups/2-hr session) and mean group size. Frequency of groups (%) was calculated by age composition (i.e., all adult, all juvenile, mixed) and sex composition (i.e., all male, all female, mixed) among trail and trail condition classes. Student’s *t*-tests investigated use by time of day. Tests were significant when $p \leq 0.05$. To quantify disturbance at the shelter, I calculated the frequency of groups (%) that entered or disturbed the shelter along the Upper Loop. Patterns in sex and age class associated with disturbance at the shelter were then examined.

Four methods assessed patterns of shelter use by bats: flight activity, emergence counts, roost surveys, and recovery of discarded moth wings on the shelter floor. Observation using a night vision viewer (210 Technology, ITT Night Vision, Roanoke, Va., USA) and Wheat lamps with infrared filters (Wratten #87, Eastman Kodak) of bat activity at the shelter provided the number of bats entering and exiting the shel-

ter for one hour post-sunset on 11 and 26 April, 16 May, 20 and 28 June, and 12 July 1998. Recorded flight activity data included the number of bats observed entering and exiting per hour; and emergence counts as the minimum known number of bats observed (# exiting - # entering) per count.

Roost surveys were completed on 25 March, 11 April, 24 May, 28 June, 25 July, 2 and 8 August, and 13 and 20 September 1998. All bats observed were recorded by species, with attention paid to any presence of non-volant young. These data were combined with levels of flight activity and emergence counts to develop a semi-monthly profile of use by bats. Recovery of all freshly discarded moth wings from the floor of the outer room of the shelter on the same day roost counts were conducted provided an index to feeding activity of *Corynorhinus rafinesquii*. The species is a "moth specialist" in Kentucky (Hurst & Lacki 1997).

RESULTS

Visitor use of the trails did not vary by time of sampling for either passage rate ($t = 0.86$; $p = 0.39$; df = 46; equal variances) or group size ($t = 0.28$; $p = 0.78$; df = 88; equal variances). Visitor use of the trails increased as the season progressed (Table 1), probably due to the enhanced access after the trail clearing of the Upper Loop ($F = 9.72$; $p = 0.0032$) between 28 June and 12 July, although passage rate remained higher on Reubens Cutoff than along the Upper Loop ($F = 17.7$; $p = 0.0001$). The interaction between effects was not significant ($F = 2.43$; $p = 0.1261$). Group size did not vary by either trail condition ($F = 0.12$; $p = 0.73$) or trail used ($F = 0.94$; $p = 0.34$). However, because only 20% (18/90) of the groups used the Upper Loop, data indicate that Reubens Cutoff reduced visitor exposure to the shelter.

Table 1. Use of Trails by Visitors at Natural Bridge State Park, Powell County, Kentucky, from April to September 1998.

Parameter/Trail	Trail Condition: Limited Access (April - June) Mean ± SE (n)*	Trail Condition: Free Access (July - September) Mean ± SE (n)
Passage rate (# groups/ 2 hr)		
Upper Loop	0.33 ± 0.65 (12)	1.17 ± 1.27 (12)
Reubens Cutoff	1.75 ± 1.42 (12)	4.25 ± 3.11 (12)
Group size (#/ group)		
Upper Loop	2.75 ± 0.96 (4)	2.71 ± 1.2 (14)
Reubens Cutoff	3.28 ± 1.55 (21)	3.02 ± 1.39 (51)

*Sample size for group rate is based on the number of 2-hr sampling sessions, whereas sample size for group size is based on the number of groups observed.

Table 2. Sex and Age Composition of Groups of Visitors Using the Upper Loop and Reubens Cutoff Trails at Natural Bridge State Park, Powell County, Kentucky, from April to September 1998.

Parameter/Trail	Trail Condition: Limited Access (April - June) # / %	Trail Condition: Free Access (July - September) # / %
Upper Loop		
Female groups	0 / 0	0 / 0
Male groups	1 / 25	5 / 35.7
Mixed sexes	3 / 75	9 / 64.3
Reubens Cutoff		
Female groups	0 / 0	0 / 0
Male groups	3 / 14.3	6 / 11.8
Mixed sexes	18 / 85.7	36 / 70.6
Upper Loop		
Adult groups	3 / 75	0 / 0
Juvenile groups	0 / 0	0 / 0
Mixed ages	1 / 25	2 / 14.3
Reubens Cutoff		
Adult groups	12 / 57.2	38 / 74.5
Juvenile groups	2 / 9.5	0 / 0
Mixed ages	7 / 33.3	13 / 25.5

*Sample size for group rate is based on the number of 2-hr sampling sessions, whereas sample size for group size is based on the number of groups observed.

Patterns in sex and age composition showed that the majority of groups were of mixed sexes and comprised of adults (Table 2). Use of the trails by juveniles was low, especially for the Upper Loop where no group comprised solely of juveniles was recorded. Groups comprised exclusively of females were scarce in April, May, and June, but increased in frequency during the second half of the summer. No group comprised solely of females was observed using the Upper Loop. An adult male was present in each group that used the Upper Loop.

The frequency of entry into the shelter by Upper Loop groups was low (5.55%; n = 1), but the overall percentage of groups exhibiting behavior judged as having a potential disturbance effect was slightly higher (16.7%; n = 3). All groups exhibiting disturbance behavior were recorded prior to the clearing of debris along the Upper Loop. Perhaps the energy required to circumnavigate the debris and washouts resulted in a tendency to stop and rest once groups reached the base of the cliff where the shelter was situated.

Behaviors judged as having a disturbance effect were: flash photography, loud vocalizations, use of flashlights, discarding debris, eating a meal inside the shelter, and urination at the entrance. All those exhibiting disturbance behavior were adult groups comprised either solely of males, or both males and females. The amount of time spent at the entrance or inside the

Table 3. Use of Hood Branch Rock Shelter by Rafinesque's Big-Eared Bats in Natural Bridge State Park, Powell County, Kentucky, 1998.

Sampling Date	Activity (Bats/ hr)	Emergence Count (# bats)	Roost Count (# bats)	Discarded Moth Wings (n)
25 Mar			0	6
11 Apr	1	0	0	3
26 Apr	19	4		
16 May	48	18		
24 May			17	29
20 Jun	45	19		
28 Jun	53	33	16 (young)	41
12 Jul	94	4		
25 Jul			0	47
2 Aug			0	3
8 Aug			1	7
13 Sep			1	0
20 Sep			1	21

shelter by those groups exhibiting disturbance behavior was between 16 and 31 minutes.

Four of the five sampling dates showed the shelter was entered, with no evidence of entry detected on 20 September, the final date of sampling. However, floor surveys indicated the shelter was regularly entered outside of sampling sessions. The average frequency of rocks showing sign of entry was 32%. The survey on 25 July discovered a small fire had been built inside the shelter sometime after the 12 July visit. Data from floor surveys indicate disturbance rates based on weekend sampling sessions alone underestimated the level of disturbance, as weekend sampling sessions detected no obvious disturbance in July, August, or September. Perhaps entry into the shelter is more frequent on weekdays when overall visitation is low, as likelihood of being "caught" inside the shelter by park personnel or other passing trail visitors is lower.

Two species of bats, *Corynorhinus rafinesquii* and *Myotis septentrionalis* (northern bat), use the shelter during this study. The lone *M. septentrionalis*, identified by its smaller size and its gleaning behavior inside the outer room of the shelter, was seen on the evening of 12 July. Additional evidence of use by species other than *C. rafinesquii* was not recorded. No bat was observed during the initial visit on 25 March (Table 3). However, evidence of use was prevalent in the form of discarded moth wings and scattered fecal remains. Bat activity at the entrance to the shelter was observed on 26 April and increased to a peak on 12 July.

Observation of a cluster of this species roosting on the back side of an overhang to the right of the domed ceiling in the rear room on 16 May confirmed use of the shelter by *Corynorhinus rafinesquii*. An emergence count later that evening produced 18 bats (Table 3). The number of *C. rafinesquii* emerging from the shelter remained stable until 28 June, when 33 were recorded. A visit inside the shelter after the emergence of bats that evening resulted in an additional 16 non-volant young hanging on the right hand side of the domed ceiling in the rear room. Whether any young had already taken flight is uncertain but suspected for several reasons. First, there was a large increase in the number of bats emerging compared with earlier sampling dates. Second, there was extensive flight activity at the entrance to the shelter, some of which appeared erratic and potentially attributable to young bats learning to fly. Third, the non-volant young observed inside the shelter appeared to be in the late stages of development. Regardless, the combined population estimate of 49 for the colony of *C. rafinesquii* was the largest ever recorded at the shelter.

Bat activity remained high at the shelter on 12 July, but the emergence count resulted in only 4 bats, indicating the original colony had abandoned the shelter and *Corynorhinus rafinesquii* were coming from another roosting site (Table 3). A visit inside the shelter on 25 July showed bats used the site but were not present, despite an extensive number of discarded moth wings on the shelter floor. Subsequent visits on 2 and 8 August, and 13 and 20 September never resulted in more than a single *C. rafinesquii* roosting inside the shelter.

DISCUSSION

Corynorhinus rafinesquii used the shelter as both a feeding and a maternity roost in summer 1998. Further, the size of the colony, and especially the number of young observed, suggest that this shelter is an important maternity site of this species in Kentucky. Observations also indicate that shelter abandonment in early to mid-July was associated with increased use of the Upper Loop Trail by park visitors and disturbance inside the shelter. Although direct cause and effect cannot be positively discerned from these data, the documentation of disturbance suggests that use of the shelter by *C. rafinesquii* was inhibited by park visitors.

Data indicate that Reubens Cutoff did steer a high percentage of users of Hood Branch Trail off the Upper Loop and away from the shelter, although human disturbance was documented throughout most of the sampling period. Further, the presence of a posted sign at the shelter entrance did not provide sufficient deterrence to some park visitors, particularly groups that included adult males.

In contrast to mammals of similar size, bats have small litters and extended periods of infant dependency (Findley 1993), which places bats at risk of population decline when subject to habitat alteration. Reproductive rates are not density dependent and cannot offset the increased mortality of adults that occurs when roosting habitats are altered or lost. Disturbance at roosting sites is believed to be the most significant factor in the decline of bat populations in North America, particularly for bats that do not roost in man-made structures (Barbour & Davis 1969; Harvey 1976; Humphrey & Kunz 1976).

Females of *Corynorhinus rafinesquii* give birth to only a single young per growing season (Jones 1977), making this species extremely vulnerable to disturbance at maternity sites.

Although *C. rafinesquii* roost in a variety of natural and man-made structures, including trees, limestone caves, unoccupied buildings, mines, old cisterns, bridges, and culverts (Barbour & Davis 1969, 1974; Jones 1977), the majority of summer colonies in Kentucky are in sandstone rock shelters in summer (Hurst 1997; J. MacGregor, U.S. Forest Service, unpub. data). Thus, adequate protection of these roosting shelters is crucial to the long-term conservation of this species in Kentucky. *Corynorhinus rafinesquii* was formerly listed as a federal Category 2 candidate species by the U.S. Fish and Wildlife Service (Federal Register Vol. 50, No. 181, p. 37965), and is currently listed as a threatened species in Kentucky (KSNPC 1996).

There is no legal mandate to protect this bat in Kentucky as *Corynorhinus rafinesquii* is not currently afforded federal protection under the Endangered Species Act of 1973, and the state of Kentucky does not officially recognize its own existing state list of threatened and endangered species. Consequently, further declines in the numbers of this species are imminent unless land stewards choose to be proactive and institute conservation measures. Based on these data, existing strategies of Natural Bridge State Park personnel to protect *C. rafinesquii* (e.g., alternate hiking route, posted sign and wooden fence at the entrance to the shelter) appear inadequate to prevent disturbance by park visitors at the maternity roost, regardless of whether disturbance is unintentional or not. Given that other colonies of *C. rafinesquii* in Kentucky are known to be philopatric to a single maternity roost throughout summer (Hurst 1997; Hurst & Lacki 1999), protection of bats using Hood Branch Rock Shelter from human disturbance throughout the maternity season is essential if this roosting site is to remain a suitable maternity habitat of this species.

RECOMMENDATIONS

Options available for the protection of this roosting site include: maintaining existing policies and protective measures, the construction of a gate or fence to prohibit entrance into the shelter, or closure of the Upper Loop Trail to park visitors. Existing policies and protective measures are inadequate. In fact, placement of a sign at an entrance to a roosting site may actually serve as a stimulus for entry (MacGregor 1991). Construction of a gate or fence requires considerable cost and is usually implemented primarily at roosting sites of bats afforded federal protection under the Endangered Species Act, with funds obtained through federal sources. Unfortunately, placement of gates has in some instances resulted in declines in bat populations due to a variety of factors, including changes in roost microclimate, increased vulnerability to predators, or flying mishaps by bats attempting to negotiate their way past the gate (Tuttle 1977, 1986; Richter *et al.* 1993).

Closure of the Upper Loop Trail appears the most viable option for protecting *Corynorhinus rafinesquii* in Hood Branch Rock Shelter. Closure would not necessarily have to be permanent, but could be restricted from 15 May to 15 August, the length of the maternity season of *C. rafinesquii* (Jones 1977; Hurst & Lacki 1999). This would protect bats during the maternity season, while opening up the trail to park visitors throughout the remainder of the year. Costs of this strategy include placement of signs at the two entry points to the trail and supplemental enforcement by park personnel. Further, use of educational programs and materials provided at the entrance to Hood Branch Trail could justify to park visitors the need to stay off the Upper Loop Trail during the prohibited time period. Because of a long history of man's persecution of bats, public education is considered a critical element in the long-term conservation of North American bats (Tuttle 1979; ASM 1992; Fenton 1997), and is a proactive measure recommended for use at Natural Bridge State Park, Kentucky.

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Will K. Reeves, John B. Jensen and James C. Ozier - New Faunal and Fungal Records from Caves in Georgia, USA. *Journal of Cave and Karst Studies 62*(3): 169-179.

NEW FAUNAL AND FUNGAL RECORDS FROM CAVES IN GEORGIA, USA

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Records for 173 cavernicolous invertebrate species of Platyhelminthes, Nematoda, Nemertea, Annelida, Mollusca, and Arthropoda from 47 caves in Georgia are presented. The checklist includes eight species of cave-dwelling cellular slime molds and endosymbiotic trichomycete fungi associated with cave millipedes and isopods.

The cave fauna of Georgia has attracted less attention than that of neighboring Alabama and Tennessee, yet Georgia contains many unique cave systems. Limestone caves are found in two geological regions of the state, the Coastal Plain, and the Appalachian Plateau and Valley. Over five hundred caves in Georgia are known, but biological information has been reported for less than 15%.

Culver *et al.* (1999) reviewed the distributions of cavernicoles in the United States. Their records of obligate cave dwellers in Georgia were significantly less than records for adjacent counties of Alabama and Tennessee. Holsinger and Peck (1971) reviewed the cave faunal records of Georgia and included their own collection records in an annotated checklist. Since that publication, new records and species descriptions have been published. As indicated by Gosz (1999), the longer the sampling effort in a biodiversity survey, the more likely rare or seasonal species will be collected. The objective of our paper is to update the cave faunal and fungal records in Georgia by reporting recently collected material and reviewing relevant literature published after Holsinger and Peck (1971).

MATERIALS AND METHODS

Specimens were collected opportunistically by hand, baiting, and processing detritus in Berlese funnels. Baits included canned cat food, chicken liver, dung, rotten apples, and cheese. Trichomycete fungal hosts were collected alive and processed using the techniques of Lichtwardt (1986). Cellular slime molds were cultured at Shepherd College using the techniques of Landolt *et. al*. (1992)

The ecological classification after species names of cavernicolous organisms refers to levels of cave specificity, as defined by Barr (1963) with modifications to include edaphobiies and symbiotes. The notations are (TB) troglobites, (TP) troglophiles, (TX) trogloxenes, (AC) accidentals, (ED) edaphobites, (SY) symbiotes, and (unknown). Dates are given for those species collected during field surveys. Some species were not collected repeatedly at the same site although they often were present. Therefore, collection dates do not represent the seasonal presence of those animals.

Unless otherwise noted, specimens have been deposited in the Clemson University Arthropod Collection. Other collections where specimens were deposited are abbreviated with the following four letter codes, which are listed after the species name: AMNH-American Museum of Natural History; CAAS-California Academy of Science; CARL-Carleton University (Canada); CARN-Carnegie Museum of Natural History; DEIC-Deutsches Entomologisches Institut (Germany); FSCA-Florida State Collection of Arthropods; GASO-Georgia Southern University Collection; JCCK-James Cokendolpher Personal Collection; LANH-Los Angeles County Museum of Natural History; LSUC-Louisiana State University Collection; MAXP-Max Planck Institute (Germany); NCRL-Natural Resources Canada Laurentian Forestry Centre (Canada); OHIO-Ohio State University; OLDM-Old Dominion University; SMIT-Smithsonian Institute; SYDH-Hampden-Sydney College; UGAM-University of Georgia Natural History Museum; UMAA-University of Michigan at Ann Arbor; UMON-University of Montana; USNT-United States National Tick Collection; UTEN-University of Tennessee; VMNH-Virginia Museum of Natural History; WITT-Wittenberg University.

The annotated list of species is organized phylogenetically by phylum and class following Holsinger and Peck (1971). The cellular slime molds and symbiotic trichomycete fungi are listed first because they do not fall into an animal phylogeny. Orders and all other taxonomic categories are organized alphabetically. The investigated caves are listed alphabetically by county. Those caves that were not surveyed in this study but are referenced in the literature and included for the updated faunal list are noted with an asterisk (*). Approximate cave locations are indicated in figure 1.

Investigated Georgia caves include; Bartow Co.-Anthonys Cave, Busch Cave, Chert Chasm, Kingston Saltpeter Cave, Ladds Lime Cave, Yarborough Cave; Chattooga Co.-Blowing Springs Cave*, Parkers Cave*; Dade Co.-Boxcan Cave*, Byers Cave*, Case Cavern*, Cemetery Pit, Deans Pit, Goat Cave, Howards Waterfall Cave, Hurricane Cave, Johnsons Crook Cave, Morrison Cave*, Morrison Springs Cave*, Newsome Gap Cave, Quarry Cave, Rising Fawn Cave*, Rock

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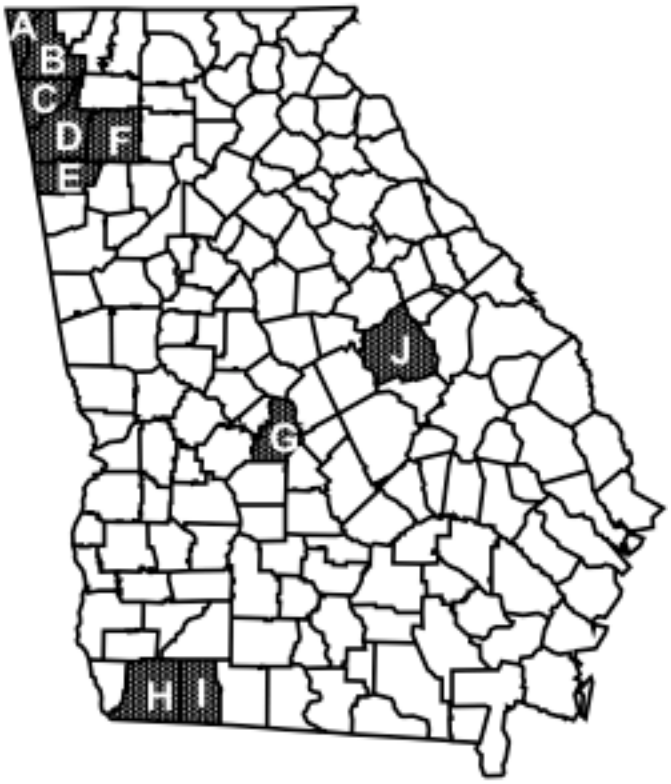


Figure 1. Distribution of Georgia caves investigated. A= Dade County (19 caves), B= Walker County (14 caves), C= Chattooga County (2 caves), D= Floyd County (1 cave), E= Polk County (1 cave), F= Bartow County (6 caves), G= Houston County (1 cave), H= Decatur County (1 cave), I= Grady County (1 cave), J= Washington County (1 cave).

Shelter Pit, Rustys Cave, Sittons Cave, Twin Snakes Cave* (Limestone Caverns), Upper Valley Cave; Decatur Co.-Climax Cave; Floyd Co.-Cave Springs Cave*; Grady Co.-Maloys Waterfall Cave; Houston Co.-Limerock Cave*; Polk Co.-White River Cave*; Walker Co.-Anderson Spring Cave, Bible Springs Cave*, Cave Springs Cave*, Chickamagua Cave Spring Cave*, Ellisons Cave, Fricks Cave, Harrisburg Caves*, Hickman Gulf Cave*, Horseshoe Cave, Mt. Cove Farm Cave*, Nash Waterfall Pit, Pettijohns Cave, Spooky Cave, Rocky Cave; Washington Co.-Tennille Lime Sinks.

ANNOTATED LIST

Division Myxomycota
Class Acrasiomycetes
Order Dictyosteliales
Family Dictyosteliaceae

Dictyostelium giganteum Singh, *D. mucoroides* Brefeld, *D. purpureum* Olive, and *D. sphaerocephalum* (Oud) (unknown)

Dade Co.: Sittons Cave, 22 October 1999.

Comments: Four cellular slime molds were cultured from a soil sample collected in Sittons Cave. Cellular slime molds are considered primarily leaf-litter organisms, but several species have been reported from caves in West Virginia (Landolt *et. al* 1992). All records are presented under one heading because the collections were made at the same time in the same location.

Dictyostelium aureo-stipes Cavender, Raper and Norberg and *Polysphondylium violaceum* Brefeld (unknown)

Dade Co.: Sittons Cave, 22 October 1999, Rustys Cave, 30 January 2000.

Comments: These two slime molds were cultured from soils in both caves. These species are common surface and cave dwelling slime molds.

Division Zygomycota
Class Trichomycetes

Trichomycetes are endosymbiotic gut fungi associated with arthropods. Trichomycetes are believed to have an obligate association with their hosts and cannot grow, metabolize, or reproduce in environments outside their host (Lichwardt 1986). Trichomycetes have not been reported in previous cave faunal lists, but probably are found in cavernicolous amphipods, crayfish, isopods, and millipedes.

Order Eccrinales
Family Eccrinaceae

Enterobryus oxidi Lichtwardt (SY)

Dade Co.: Howards Waterfall Cave

Comments: This fungus was found in the hindgut of *Oxidus gracilis* (Koch), a common troglophilic millipede in Howards Waterfall Cave. *Enterobryus oxidi* is the only trichomycete known to associate with *O. gracilis* (Lichtwardt 1986).

Enterobryus spp. (SY)

Bartow Co.: Kingston Saltpeter Cave; Dade Co.: Sittons Cave, Johnsons Crook Cave, Howards Waterfall Cave, Hurricane Cave; Walker Co.: Horseshoe Cave, Fricks Cave, Pettijohns Cave.

Comments: Several unidentified *Enterobryus* spp. were removed from the hindguts of the cavernicolous millipedes *Cambala annulata, C. hubrichti, C. ochra, Pseudotremia eburnea*, and *Scoterpes austrinus*, and the troglobitic isopod *Caecidotea richardsonae*. These records probably represent several new species of trichomycetes and, except for the *Caecidotea*, are new host-genus records.

Phylum Platyhelminthes
Class Turbellaria
Order Tricladida
Family Kenkiidae

Sphalloplana spp. (TB)

Dade Co.: Hurricane Cave, 10 December 1998; Walker Co.: Anderson Spring Cave, 1 January 1999.

Comments: These collections might represent undescribed species. Only *S. georgiana* Hyman was known previously in Georgia (Kenk 1976; Carpenter 1970).

Phylum Nematoda
Class Adenophorea
Order Mermithida
Family Mermithidae

Unidentified genus and species (SY)

Dade Co.: Howards Waterfall Cave, 26 December 1998.

Comments: Immature mermithids can not be identified. These endoparasitic nematodes were collected in Howards Waterfall Cave. The host organism was a troglobitic millipede, *Pseudotremia eburnea*.

Class Rhabditae
Order Oxyurida
Family Thelastomatidae

Unidentified genus and species (SY)

Walker Co.: Fricks Cave, 11 December 1998.

Comments: These nematodes were found in the guts of cave millipedes, *Cambala hubrichti*. Unlike mermithids, thelastomatids are not always destructive to their hosts.

Phylum Nemertea
Class Enopla
Order Hoplonemertea
Family Tetrastemmatidae

Prostoma cf *graecense* (Bohmig) (unknown) SMIT

Dade Co.: Howards Waterfall Cave, 10 December 1998.

Comments: Nemerteans are usually overlooked by aquatic biologists. These

worms have not been reported in cave streams and this specimen might represent an undescribed species. According to Pennak (1978), several undescribed species of *Prostoma* have been collected in the continental USA.

Phylum Annelida
Class Clitellata
Order Branchiobdellida
Family Branchiobdellidae

Undetermined genus and species (SY)
Dade Co.: Howards Waterfall Cave, 10 December 1998; Hurricane Cave, 10 December 1998; Washington Co: Tennille Lime Sinks, 24 May 2000.
Comments: These symbionts were found on the exoskeleton of cave-dwelling crayfish and were reported by Reeves and Reynolds (1999). Several species of branchiobdellids can be found on a single host (Hobbs *et al.* 1967).

Undetermined material
Decatur Co.: Climax Cave.
Comments: Several undetermined species of Branchiobdellida were reported by Holt (1973).

Order Oligochaeta

Earthworms and other annelids are only sometimes collected during cave surveys; however, several species are troglophilic or troglobitic (Peck 1998; Reynolds 1996).

Family Lumbricidae

Aporrectodea sp. (TP)
Walker Co.: Spooky Cave, 19 March 1999.
Comments: This immature worm was reported by Reeves and Reynolds (1999).

Aporrectodea trapezoides Duges (TP)
Dade Co.: Howards Waterfall Cave, 29 January 1999; Walker Co.: Horseshoe Cave, 16 August 1998 and 19 May 1999.
Comments: An immature and albino adult earthworm was reported by Reeves and Reynolds (1999) in Horseshoe Cave.

Bimastos tumidus (Eisen) (TP)
Bartow Co.: Kingston Saltpeter Cave, 2 June 1999.
Comments: This endemic earthworm was reported by Reeves and Reynolds (1999)

Dendrodrilus rubidus (Savigny) (TP)
Dade Co.: Howards Waterfall Cave, 10 December 1998, Hurricane Cave, 10 December 1998; Decatur Co.: Climax Cave, 6 March 1999; Walker Co.: Goat Cave, 19 May 1999, Horseshoe Cave, 16 August 1998.
Comments: This earthworm was reported by Reeves and Reynolds (1999). *Dendrodrilus rubidus* is preadapted to cave life (Gates 1959).

Lumbricus rubellus Hoffmeister (ED)
Bartow Co.: Anthonys Cave, 20 May 1999; Dade Co.: Howards Waterfall Cave, 10 January 1999; Walker Co.: Horseshoe Cave, 19 May 1999.
Comments: This earthworm was reported by Reeves and Reynolds (1999).

Family Megascolecidae

Amynthas minimus (Horst) (ED)
Dade Co.: Howards Waterfall Cave, 29 January 1999.
Comments: This megascolecid earthworm was reported by Reeves and Reynolds (1999). It is an exotic Asian earthworm (Reynolds 1978).

Family Naididae

Arcteonais lomondi (Martin) (TP)
Bartow Co.: Anthonys Cave, 20 May 1999.
Comments: This aquatic oligochaete was collected in a drip pool with mammal feces.

Phylum Mollusca
Class Gastropoda
Order Stylomnatophora
Family Polygyridae

Mesodon sp. (unknown) OHIO
Walker Co.: Anderson Springs Cave, 9 May 1999.
Comments: Immature snails were collected in a boulder pile. Some *Mesodon* species inhabit dark overhung and rocky habitats like caves (Hubricht 1985).

Triodopsis or *Mesodon* sp. (unknown) OHIO
Bartow Co.: Busch Cave, 2 June 1999.
Comments: Juvenile specimens were collected in organic debris near an entrance.

Family Zonitidae

Glyphyalinia cryptomphala (Clapp) (TP) OHIO
Dade Co.: Upper Valley Cave, 10 May 1999.
Comments: This small snail was crawling on the roof of the cave in the dark zone.

Glyphyalinia praecox (Baker) (unknown) OHIO
Bartow Co.: Anthonys Cave, 20 May 1999.
Comments: This small snail was collected in the dark zone of the cave.

Glyphyalinia rhoadsi (Pilsbry) (unknown) OHIO
Washington Co.: Tennille Lime Sinks, 24 May 2000.
Comments: Five snails were collected in a dry area with decaying woody debris.

Glyphyalinia sculptilis (Bland) (TX) OHIO
Bartow Co.: Busch Cave, 2 June 1999; Walker Co.: Rocky Cave, 19 March 1999, Spooky Cave, 19 March 1999.
Comments: This snail was collected in debris piles near the cave entrances.

Hawaiia miniuscula (Binney) (TP) OHIO
Dade Co.: Howards Waterfall Cave.
Comments: This snail was collected in organic debris. *Hawaiia miniuscula* was the most common cave snail reported in Mexican caves (Reddell 1981) and is thus a probable troglophile.

Ventridens gularis (Say) (TP) OHIO
Walker Co.: Horseshoe Cave, 19 May 1999.
Comments: This snail was collected on the roof of the cave.

Ventridens sp. (unknown) OHIO
Walker Co.: Horseshoe Cave, 16 August 1998.
Comments: This record potentially represents an undescribed species, but an adult of *Ventridens gularis* was also collected in the cave.

Zonitoides arboreus (Say) (unknown) OHIO
Decatur Co.: Climax Cave, 6 March 1999; Grady Co.: Maloys Waterfall Cave, 5 March 1999.
Comments: This species is widely distributed in Georgia (Hubricht 1964, 1985).

Phylum Arthropoda
Class Crustacea
Order Amphipoda
Family Gammaridae

Crangonyx antennatus Packard (TB) OLDM
Dade Co.: Cemetery Pit, 10 March 1999, Rustys Cave, 17 December 1998, 1 February 2000, Spooky Cave, 19 March 1999, Upper Valley Cave, 10 March 1999; Walker Co.: Anderson Springs Cave, 9 May 1999.
Comments: This amphipod was repeatedly collected in Georgia's caves.

Stygobromus ackeriyi Holsinger (TB) OLDM
Bartow Co.: Chert Chasm, 1 April 1999; Floyd Co.: Cave Springs Cave; Polk Co.: White River Cave.
Comments: Holsinger (1978) described and presented the Georgia records of this species, except for our collections in Chert Chasm.

Stygobromus dicksoni Holsinger (TB)
Chattooga Co.: Blowing Springs Cave; Dade Co.: Byers Cave, Cemetery Pit, 10 March 1999, Howards Waterfall Cave, Rustys Cave; Walker Co.: Pettijohns Cave.
Comments: Holsinger (1978) described and presented the Georgia records of this species. We made an additional collection in Cemetery Pit.

Stygobromus grandis Holsinger (TB)
Chattooga Co.: Parker Cave.
Comments: Holsinger (1978) described and presented the Georgia records of this species.

Stygobromus minutus Holsinger (TB)
Walker Co.: Pettijohns Cave.
Comments: Holsinger (1978) described and presented the Georgia records of this species.

Order Cladocera
Family Daphnidae

Daphnia sp. (unknown)
Bartow Co.: Anthonys Cave, 20 May 1999
Comments: This daphnid was collected in drip pools with mammal dung.

Order Copepoda
Family Canthocamptidae

Attheyella illinoisensis (Forbes) (unknown)
Washington Co.: Tennille Lime Sinks, 24 May 2000.

Comments: This copepod was collected in the cave silt.

Attheyella nordenskioldi (Lilljeborg) (AC)
Dade Co.: Howards Waterfall Cave, 12 February 1999; Walker Co.: Horseshoe Cave, 19 May 1999.
Comments: This copepod probably entered the caves during rainstorms and represents accidental cave fauna.

Elaphoidella bidens (Schmeil) (unknown)
Washington Co.: Tennille Lime Sinks, 24 May 2000.
Comments: This copepod was collected in the cave silt.

Family Cyclopidae

Acanthocyclops robustus (Fischer) (TP)
Bartow Co.: Anthonys Cave, 20 June 1999.
Comments: This copepod was collected in drip pools with mammal dung.

Eucyclops conrowae Reid (unknown)
Washington Co.: Tennille Lime Sinks, 24 May 2000.
Comments: This copepod was collected in the cave silt.

Eucyclops elegans (Herrick) (TP)
Bartow Co.: Anthonys Cave, 20 June 1999.
Comments: This copepod was collected in drip pools with mammal dung.

Macrocyclops albidus (Jurine) (TP)
Bartow Co.: Anthonys Cave, 20 June 1999.
Comments: This copepod was collected in drip pools with mammal dung.

Order Decapoda

Family Astacidae

Cambarus bartonii (Fabricius) (TP)
Dade Co.: Twin Snakes Cave.
Comments: Hobbs (1981) reported this cave crayfish record.

Cambarus striatus Hay (TP) WITT
Chattooga Co.: Blowing Springs Cave; Walker Co.: Bible Springs Cave, Horseshoe Cave, August 1998.
Comments: Holsinger and Peck (1971) reported some of these records as *Cambarus* sp. and they were later identified by Hobbs *et al.* (1977).

Cambarus tenebrosus Hay (TP) WITT
Dade Co.: Howards Waterfall Cave, 10 December 1998, Hurricane Cave, 10 December 1998.
Comments: This crayfish is common in the streams and pools of these caves.

Order Isopoda

Family Asellidae

Caecidotea spp. (TB)
Comments: Records for several species were presented by Buhlmann (1996) in an unpublished report to the State Department of Natural Resources.

Family Oniscidae

Cylisticus convexus (DeGreer) (TX) SYDH
Bartow Co.: Anthonys Cave, 21 May 1999; Dade Co.: Howards Waterfall Cave, 10 December 1998, 5 January 1999, 29 January 1999; Walker Co.: Horseshoe Cave, 16 August 1998.
Comments: This imported European isopod was collected near cave entrances or elsewhere in the caves after rains.

Family Trichoniscidae

Miktoniscus spp. (TB)
Bartow Co.: Anthonys Cave, 20 May 1999; Dade Co.: Howards Waterfall Cave, 10 December 1998, 6 August 1998, Sittons Cave, 6 August 1998; Walker Co.: Horseshoe Cave, 16 August 1998, Spooky Cave, 19 March 1999.
Comments: These troglobites were found on the mud flats of Anthonys, Horseshoe, and Sittons caves and along the drip pools of Howards Waterfall Cave. Shear (pers. comm. 1999) believes that they might represent an undescribed species.

Order Ostracoda

Family Candoniidae

Pseudocandona sp. (unknown)
Dade Co.: Rustys Cave, 1 February 2000.
Comments: Two ostracods were collected in the cave stream.

Family Cypridopsidae

Potamocypris cf. *fulva* (unknown)
Walker Co.: Horseshoe Cave, 19 May 1999.
Comments: This ostracod was collected in a plankton net.

Family Entocytheridae

Uncinocythere warreni Hobbs and Walton (SY)
Decatur Co.: Climax Cave.
Comments: Entocytherids are symbionts of troglobitic decapods. These ostracods were reported to live on *Cambarus cryptodytes* by Hobbs *et al.* (1977).

Class Arachnida

Order Acarina

Family Acaridae

Troglocoptes sp. (TB) UMAA
Walker Co.: Fricks Cave, 11 December 1998.
Comments: This undescribed troglobitic mite lives in *Myotis grisescens* guano.

Family Argasidae

Carios kelleyi (Cooley and Kohls) (SY) USNT
Decatur Co.: Climax Cave, 6 March 1999.
Comments: A fully engorged nymphal bat tick was collected in guano piles. The host bat is likely *Myotis austroriparius*. Unlike the hard ticks (Ixodidae), this species feeds on its host only intermittently and breeds in caves.

Family Ixodidae

Dermacentor variabilis (Say) (SY) USNT
Dade Co.: Howards Waterfall Cave, 26 December 1998.
Comments: An adult tick was collected under a wooden plank in the cave, probably having dropped from a small mammal.

Ixodes cookei Packard (SY) USNT
Walker Co.: Rocky Cave, 19 March 1999.
Comments: This is a common eastern tick that feeds on marmots, beavers, porcupines, cows, humans, and owls (Gregson 1982).

Family Laelapidae

Laelaspis sp. (TP) OHIO
Walker Co.: Pettijohns Cave, 15 July 1995; Dade Co.: Case Cave, 26 August 1995
Comments: Only female mites were collected.

Family Macrochelidae

Macrocheles sp. (TP) UMAA, OHIO
Walker Co.: Fricks Cave, 16 September 1995, 11 December 1998.
Comments: This mite was common in guano of *Myotis grisescens*.

Family Trombiculidae

Euschoengastia pipistrelli Brennan (SY) GASO
Dade Co.: Howards Waterfall Cave, 10 December 1998; Walker Co.: Fricks Cave, 11 December 1998.
Comments: This species of chigger was ectoparasitic on *Pipistrellus subflavus*, living in the ears and on the face.

Leptotrombidium myotis (Ewing) (SY) GASO
Bartow Co.: Anthonys Cave, 20 May 1999.
Comments: This chigger was found feeding in the ear of *Pipistrellus subflavus*.

Family Veigaidae

Veigaia sp. (unknown) OHIO
Walker Co.: Nash Waterfall Pit, 5 August 1995.
Comments: The single specimen collected did not appear to be troglomorphic.

Undetermined genus and species (unknown)
Walker Co.: Horseshoe Cave, 12 October 1998.
Comments: Two female mites were collected in cave debris.

Order Araneae

Family Agelenidae

Calymmaria cavicola (Banks) (TP)
Dade Co.: Rustys Cave, 18 October 1998 and 17 December 1998.
Comments: On 18 October 1998, a pair of these troglophilic spiders was collected while they mated.

Family Antrodiaetidae

Antrodiaetus unicolor (Hentz) (TP) SMIT
Dade Co.: Howards Waterfall Cave, 29 January 1999; Walker Co.: Fricks Cave, 11 December 1998.
Comments: Small populations of this trap door spider were found near the guano slopes deep in Fricks Cave. All age classes were present, which indicated a viable breeding population. A single spider was found in Howards Waterfall Cave.

Family Clubionidae

Elaver exceptus (L. Koch) (TP) AMNH

Dade Co.: Upper Valley Cave, 10 March 1999.

Comments: This spider was collected in the rubble piles near the entrance pit.

Family Leptonetidae

Appaleptoneta fiskei (Gertsch) (TB)

Walker Co.: Pettijohns Cave, Harrisburg Cave.

Comments: Gertsch (1974) reported these records.

Appaleptoneta georgia (Gertsch) (TB)

Dade Co.: Byers Cave.

Comments: Gertsch (1974) reported this record.

Family Linyphiidae

Anthrobia sp. (TP/TB) AMNH

Bartow Co.: Kingston Saltpeter Cave, 2 June 1999.

Comments: This unidentifiable, pale, eyeless spider might represent a new species. No males were collected, which precludes a definitive species identification. Only one species, *A. mammouthia* Tellkampf, has been described and it is known from Mammoth Cave, Kentucky (Roth 1993).

Erigone maculata (Banks) (TP) AMNH

Bartow Co: Busch Cave, 2 June 1999; Decatur Co.: Climax Cave, 6 March 1999; Grady Co.: Maloys Waterfall Cave, 5 March 1999.

Comments: This linyphiid lives in bat guano and under loose rocks.

Family Lycoside

Pirata insularis Emerton (unknown) SMIT

Grady Co.: Maloys Waterfall Cave, 5 March 1999.

Comments: A pair of these wolf spiders was collected in the cave.

Family Hypochilidae

Hypochilus thorelli Marx (TX/AC)

Dade Co. Boxcan Cave, Sittons Cave, 3 November 1998.

Comments: Forester *et al.* (1987) noted the Boxcan Cave record. These spiders were frequently found in the entrances of Sittons Cave.

Family Nesticidae

Eidmannella pallida (Emerton) (TP)

Dade Co.: Howards Waterfall Cave, 21 December 1998; Decatur Co.: Climax Cave, 6 March 1999.

Comments: This species of nesticid is common in the Nearctic region, Hawaii, and Europe (Gertsch 1984).

Gaucelmus augustinus Keyserling (TP)

Decatur Co.: Climax Cave, 6 March 1999; Houston Co.: Limerock Cave; Washington Co.: Tennille Lime Sinks 24 May 2000.

Comments: Gertsch (1984) noted the Limerock Cave record. *Gaucelmus augustinus* occurs frequently in coastal plain caves from South Carolina to Mexico (Reeves 1999).

Nesticus georgia Gertsch (TB)

Dade Co.: Sittons Cave, Case Caverns, unnamed cave near Trenton.

Comments: Gertsch (1984) presented these records. We observed individuals of *N. georgia* up to 600 m from the entrance. Females with egg sacs were in Sittons Cave on 7 and 16 August 1998 (Reeves 1999).

Family Pholcidae

Pholcus spp. (TX/TP) SMIT

Bartow Co.: Ladds Lime Cave, 31 July 1998; Dade Co.: Hurricane Cave, 10 December 1998, Sittons Cave, 14 January 1998, 7 August 1998, 16 August 1998; Walker Co.: Fricks Cave, 11 December 1998, Spooky Cave, 19 March 1999.

Comments: These records represent several undescribed species of *Pholcus*. Individuals were collected near the entrances to the caves in complete darkness. *Pholcus* spp. webs were built on the ceilings of the caves. The species at Ladds Lime Caves had egg sacs on 31 July 1998.

Family Tengellidae

Liocranoides gertschi Platnick (TP) AMNH

Dade Co.: Byers Cave 18 June 1967, Hurricane Cave, 10 December 1998, Sittons Cave, January 1998; Walker Co.: Horseshoe Cave, 19 May 1999.

Comments: This recently described species of *Liocranoides* was misidentified as *Liocranoides unicolor* by Holsinger and Peck (1971). *Liocranoides gertschi* was reported from both Byers and Hurricane Cave by Platnick (1999).

Family Tetragnathidae

Meta ovalis (Gertsch) (TP)

Dade Co.: Goat Cave, 19 May 1999, Howards Waterfall Cave, 10 December 1998, 27 December 1998, Sittons Cave, 7 August 1998; Walker Co.: Fricks Cave, 11 December 1998, Spooky Cave, 19 March 1999.

Comments: This species is common in cave entrances. The egg sac of a female in Howards Waterfall Cave had 105 eggs when collected on 10 December 1998, and mating was observed here on 10 and 27 December 1998. Adult spiders fed on millipedes and carabid beetles in this cave.

Family Theridiidae

Achaearanea tepidariorum (Koch) (TP/TX)

Bartow Co.: Ladds Lime Cave, 31 July 1998; Dade Co.: Sittons Cave, 28 July 1998.

Comments: This common cellar spider is an occasional troglophile and was collected near entrances. It has been reported in Alabama and Tennessee caves (Holsinger & Peck 1971).

Achaearanea sp. (TP)

Bartow Co.: Anthonys Cave, 20 May 1999.

Comments: An immature spider was collected from a web within the cave.

Family Theridiosomatidae

Theridiosoma gemmosum (L. Koch) (TX/AC)

Walker Co.: Horseshoe Cave, 16 August 1998.

Comments: This spider was found in the entrance of Horseshoe Cave.

Order Opiliones

Family Phalangodidae

Bishopella laciniosa (Crosby and Bishop) (TP)

Bartow Co.: Busch Cave, 2 June 1999; Dade Co.: Hurricane Cave, 10 December 1998, Howards Waterfall Cave, 10 December 1998, 26 December 1998; Walker Co.: Anderson Spring Cave, 1 January 1999.

Comments: Opiliones are opportunistic feeders and *B. laciniosa* probably feeds on most available organic material.

Bishopella sp. (TB) JCCK

Dade Co.: Howards Waterfall Cave, 10 December 1998.

Comments: A potentially troglobitic specimen was collected on the cave roof. This species remains unidentified but is not *B. laciniosa*.

Bishopella sp. (TP) JCCK

Bartow Co.: Anthonys Cave, 20 May 1999.

Comments: A single immature specimen was collected.

Crosbyella spinturnix (Crosby and Bishop) (TP) JCCK

Grady Co.: Maloys Waterfall Cave, 5 March 1999.

Comments: This species has been reported in other caves of south Georgia (Holsinger & Peck 1971).

Family Sabaconidae

Sabacon sp. (TP) JCCK

Walker Co.: Goat Cave, 19 May 1999.

Comments: An immature specimen was collected. This was probably an immature specimen of *Sabacon cavicolens* (Packard).

Family Sclerosomatidae

Leiobunum sp. (TX) JCCK

Bartow Co.: Anthonys Cave, 20 May 1999.

Comments: An immature specimen was collected.

Order Pseudoscorpiones

Family Chernetidae

Hesperochernes mirabilis (Banks) (TP) FSCA

Chattooga Co.: Parkers Cave; Dade Co.: Johnsons Crook Cave, Howards Waterfall Cave, Morrison Cave, and Morrison Spring Cave; Floyd Co.: Cave Springs Cave, Walker Co.: Fricks Cave, Hickman Gulf Cave, and Mt. Cove Farm Cave.

Comments: This species, reported by Muchmore (1994), was previously identified as *Pseudozaona* sp. in Holsinger and Peck (1971).

Family Chthoniidae

Apochthonius minor Muchmore (TB) FSCA

Chattooga Co.: Parkers Cave; Dade Co.: Morrison Cave.

Comments: This species, described by Muchmore (1976), was reported as *Apochthonius* sp. in Holsinger and Peck (1971).

Chthonius paludis (Chamberlin) (TP) FSCA

Walker Co.: Horseshoe Cave, 16 December 1998.

Comments: This species was collected in organic debris near a vertical entrance. *Chthonius paludis* is also found in epigean leaf litter outside caves.

Chthonius virginicus (Chamberlin) (TP) FSCA

Dade Co.: Howards Waterfall Cave, 10 December 1998.

Comments: This species was collected in accumulated organic debris along a stream corridor.

Class Symphyla

Order Symphyla

Family Scutigerellidae

Scutigerella sp. (ED)

Dade Co.: Sittons Cave, 7 August 1998.

Comments: Symphyla are common soil inhabitants that have been largely ignored taxonomically for years (Allen 1992).

Class Diplopoda

Order Chordeumida

Family Cleidogonidae

Pseudotremia aeacus Shear (TB)

Dade Co.: Hurricane Cave.

Comments: Shear (1972) described this species from Hurricane Cave.

Pseudotremia eburnea Loomis (TB) VNHM

Dade Co. Case Cavern, Cemetery Pit, 10 May 1999, Howards Waterfall Cave, 10 December 1998, 18 December 1998, 29 December 1998, 5 January 1999, Hurricane Cave, 10 December 1998, Upper Valley Cave, 10 May 1999; Walker Co.: Spooky Cave, 19 March 1999.

Comments: This species, reported in Case Cavern by Peck (1989), is a widely distributed troglobitic millipede (Hoffman 1999).

Family Trichopetalidae

Scoterpes austrinus Loomis (TB) VNHM

Bartow Co.: Busch Cave, 2 June 1999; Dade Co. Cemetery Pit, 10 May 1999, Sittons Cave, 30 September 1997, 14 January 1998, 22 May 1998, 30 July 1998, 7 August 1998, 16 August 1998, Upper Valley Cave, 10 May 1999; Walker Co.: Anderson Spring Cave, 1 January 1999, Goat Cave, 19 May 1999, Horseshoe Cave, 7 August 1998, 16 August 1998, 30 May 1998, Spooky Cave, 19 March 1999.

Comments: Holsinger and Peck (1971) could not determine the species they collected from Sittons Cave because they had immature specimens. Later collections of adult males allowed species determination. The genus *Scoterpes* is in need of taxonomic revision, and these collections might represent several species. Specimens in Sittons and Horseshoe Caves were collected on chicken liver.

Scoterpes sp. (TB) VMNH

Dade Co.: Howards Waterfall Cave, 26 December 1998.

Comments: Immature specimens were collected but could not be identified.

Order Julida

Family Blaniulidae

Blaniulus guttulus (Bosc) (ED) VNHM

Dade Co.: Howards Waterfall Cave, 10 December 1998.

Comments: *Blaniulus guttulus* is an exotic European species.

Order Polydesmida

Family Paradoxomatidae

Oxidus gracilis (Koch) (TP) VNHM

Bartow Co.: Ladds Lime Cave, 31 July 1998; Dade Co.: Howards Waterfall Cave, 10 December 1998, 26 December 1998; Decatur Co.: Climax Cave, 6 March 1999; Grady Co.: Maloys Waterfall Cave, 5 March 1999; Washington Co.: Tennille Lime Sinks, 24 May 2000.

Comments: *Oxidus gracilis* is a common introduced millipede.

Order Spirostreptida

Family Cambalidae

Cambala annulata (Say) (TX/AC) VNHM

Bartow Co.: Anthonys Cave, 20 May 1999; Dade Co.: Rustys Cave, 18 December 1998, Hurricane Cave, 10 December 1998.

Comments: This species was found near the entrance of the caves.

Cambala hubrichti Hoffman (TP) VNHM

Walker Co.: Fricks Cave, 11 December 1998, Spooky Cave, 19 March 1999.

Comments: In Fricks Cave this millipede fed on bat guano.

Cambala ochra Chamberlin (TP) VNHM

Bartow Co.: Chert Chasm, 1 April 1999; Walker Co.: Horseshoe Cave, 14 January 1998, 30 July 1998, 7 August 1998, Rocky Cave, 19 March 1999.

Comments: This species, collected on carrion in the dark zone, cannibalized injured specimens in the laboratory.

Class Insecta

Order Coleoptera

Family Cantharidae

Cantharis spp. (TX)

Chattooga Co.: Parkers Cave; Dade Co.: Quarry Cave; Walker Co.: Harrisburg Cave, Horseshoe Cave, Mt. Cove Farm Cave, and Pettijohns Cave.

Comments: According to Peck (1975), the above records understate the commonness of cantharid larvae. He believes these records may represent multiple species and that *Cantharis* spp. potentially are significant predators in caves. With the exception of our collections from Quarry and Horseshoe caves, Peck (1975) reported the records.

Family Carabidae

Atranus pubescens (Dejean) (TP) CAAS

Dade Co.: Upper Valley Cave, 10 May 1999; Decatur Co.: Climax Cave, 6 March 1999.

Comments: This beetle lives in Appalachian caves and epigean habitats.

Anillinus sp. (TP/TB/ED) CARN

Dade Co.: Hurricane Cave, 10 December 1998.

Comments: An eyeless specimen was collected under stones near the upper cave entrance.

Bembidion lacunarium Zimmerman (TP) CAAS

Dade Co.: Howards Waterfall Cave, 26 Dec 1998, Upper Valley Cave, 10 May 1999.

Comments: Specimens were collected in rocky debris around drip pools and in organic debris.

Harpalus pennsylvanicus (DeGeer) (AC) CAAS

Bartow Co.: Busch Cave, 2 June 1999.

Comments: A specimen was collected near a bird nest at the bottom of one of the vertical entrances to Busch Cave.

Paratachys sp. (TP) CAAS

Grady Co.: Maloys Waterfall Cave, 5 March 1999.

Comments: Because this genus is in need of revision, the species could not be determined from the adults collected.

Platynus parmarginatus Hamilton (AC) CARN

Walker Co.: Spooky Cave, 19 March 1999.

Comments: This beetle is a common surface species frequently found along streams.

Pseudanophthalmus digitus Valentine (TB) CARN

Dade Co.: Cemetery Pit, 10 May 1999.

Comments: A female was collected in the debris and rocks below the entrance pit. The specimen was under the same rock as a congener, *P. fulleri*.

Pseudanophtalmus fastigatus Barr (TB)

Walker Co.: Horseshoe Cave.

Comments: Barr (1981) described this species and provided the record.

Pseudanophtalmus fulleri Valentine (TB) CARN

Dade Co.: Cemetery Pit, 10 May 1999, Upper Valley Cave, 10 May 1999.

Comments: This beetle was collected in the mud and organic debris at the base of the entrance pits of both caves.

Pseudanophthalmus georgiae Barr (TB)

Chattooga Co.: Blowing Spring Cave; Walker Co.: Mt. Cove Farm Cave, Pettijohns Cave.

Comments: Barr (1981) described this species and provided the records.

Pterostichus relictus (Newman) (TX/TP) CAAS

Dade Co.: Upper Valley Cave, 10 May 1999.

Comments: A single beetle was collected in the debris piles of Upper Valley Cave.

Sphaeroderus stenostomus Weber (TX) CAAS

Dade Co.: Howards Waterfall Cave, 10 December 1998.

Comments: A specimen was collected in the web of *Meta ovalis*.

Family Histeridae

Margarinotus egreius (Casey) (TX/AC)

Walker Co.: Spooky Cave, 19 March 1999.

Comments: This beetle is usually associated with carrion.

Family Leiodidae

Catops gratiosus Blanchard (TP) CARL

Dade Co.: Johnsons Crook Cave, December 1998, Newsome Gap Cave, 29 May 1998; Walker Co.: Horseshoe Cave, 21 June 1998.

Comments: This common cave species has been found throughout the Southeast (Holsinger & Peck 1971).

Nemadus horni Hatch (TP) CARL
Dade Co.: Newsome Gap Cave, 29 May 1998. Johnsons Crook Cave, December 1998; Decatur Co.: Climax Cave, 6 March 1999; Walker Co. Rocky Cave, 19 March 1999.
Comments: The species has been reported in caves of Alabama (Peck 1995).
Ptomaphagus cavernicola Schwarz (TP) CARL
Decatur Co.: Climax Cave, 6 March 1999; Grady Co.: Maloys Waterfall Cave, 6 March 1999.
Comments: *Ptomaphagus cavernicola* is a common troglophilic leiodid near the coast. *Ptomaphagus cavernicola* was collected in Florida by Peck (1973).
Ptomaphagus fiskei Peck (TB)
Dade Co.: Anderson Spring Cave, 1 January 1999; Walker Co.: Bible Spring Cave, Mountain Cove Farm Cave, Pettijohns Cave, Rocky Cave, 19 March 1999.
Comments: With the exception of the Anderson Spring Cave and Rocky Cave records, these records were reported by Peck (1973), who determined that the species is limited to the east and west flanks of Pigeon Mountain.
Ptomaphagus whiteselli Barr (TB)
Dade Co. Cemetery Pit, 10 May 1999, Case Cavern, Hurricane Cave, 10 December 1998, Rustys Cave, 18 December 1998, and Twin Snakes Cave.
Comments: Peck (1973) reported the Case Cavern and Twin Snakes Cave records. These beetles are attracted to carrion and cheese baits.
Family Scarabaeidae
Trox aequalis Say (TP)
Walker Co.: Fricks Cave, 11 December 1998.
Comments: This scarab beetle apparently lives in guano of *Myotis grisescens* in Fricks Cave.
Family Staphylinidae
Atheta annexa Casey (TP) NRCL
Bartow Co.: Yarbrough Cave, 12 June 1967; Dade Co.: Morrison Cave, 13 July 1967; Decatur Co.: Climax Cave, 6 March 1999; Grady Co.: Maloys Waterfall Cave, 5 March 1999; Walker Co.: Chickamagua Cave Spring Cave, 10 June 1967, Horseshoe Cave, 21 June 1967, Mt. Cove Cave, 20 June 1967.
Comments: This staphylinid beetle was collected in bat guano from Maloys Waterfall Cave and Climax Cave. Klimaszewski and Peck (1986) published the additional records.
Atheta lucifuga Klimaszewski and Peck (TP)
Walker Co.: Mt. Cove Cave, 11-20 June 1967.
Comments: Klimaszewski and Peck (1986) published this record.
Atheta troglophila Klimaszewski and Peck (TP)
Dade Co.: Howard (sic) Waterfall, 30 July 1965, Byers Cave, 18 June 1967; Walker Co.: Mt. Cove Cave, 11 June 1967.
Comments: Klimaszewski and Peck (1986) published these records.
Batriasymmodes sp. (TP) LSUC
Dade Co.: Howards Waterfall Cave, 26 December 1998.
Comments: A female was collected in organic debris. *Batriasymmodes* has previously been reported as a Pselaphidae. Newton and Thayer (1995) provided evidence to move the family Pselaphidae to the Omaliinae group of the Staphylinidae.
Lesteva pallipes (LeConte) (TP) NRCL
Bartow Co.: Chert Chasm; Dade Co.: Hurricane Cave, 10 December 1998; Walker Co. Rocky Cave, 19 March 1999.
Comments: An adult was taken in the stream passages of Hurricane Cave on cat food.
Philonthus sp. (TP) NRCL
Grady Co.: Maloys Waterfall Cave, 5 March 1999.
Comments: This beetle was collected in bat guano.
Sepedophilus littoreus (Linnaeus) (TP) NRCL
Dade Co.: Horseshoe Cave, 16 August 1998.
Comments: *Sepedophilus littoreus* was collected on chicken liver.
Xenota spp. (TP)
Dade Co.: Deans Pit, January 1998, Johnsons Crook Cave, 20 March 1998; Walker Co. Horseshoe Cave, January 1998, Pettijohns Cave, 7 August 1998.
Comments: Adults of *Xenota* spp. were collected on chicken liver. Immature stages were collected in Horseshoe Cave. The specimens could not be identified to species, but they represent at least three species. One species was found in Johnsons Crook Cave and another in Pettijohns Cave. The remaining records appear to represent a third species.
Order Collembola
Family Entomobryidae
Lepidocyrtus sp. (TP)
Bartow Co.: Kingston Saltpeter Cave, 2 June 1999
Comments: This collembolan was collected in a drip pool.
Pseudosinella georgia Christiansen and Bellinger (TP) UTEN
Walker Co.: Fricks Cave, 11 December 1998.
Comments: This species was collected in fresh bat guano after processing it in a Berlese funnel.
Pseudosinella pecki Christiansen and Bellinger (TB)
Decatur, Randolph, and Stewart counties: Cave localities unreported.
Comments: Christiansen and Bellinger (1980) described this troglobitic species but did not indicate the caves in which it was collected.
Pseudosinella sp. (TB/TP) UTEN
Dade Co.: Howards Waterfall Cave, 10 December 1998, 26, December 1998.
Comments: This species does not key out to the previously reported *P. hirsuta* (Holsinger & Peck 1971), and could not be identified.
Family Neelidae
Neelus murinus Folsom (TP) UTEN
Dade Co.: Howards Waterfall Cave, 26 December 1998.
Comments: *Neelus murinus* was a common springtail in the organic debris.
Family Onychiuridae
Tullbergia iowensis Mills (TP) UTEN
Dade Co.: Howards Waterfall Cave, 10 December 1998.
Comments: *Tullbergia iowensi* was a common collembolan in organic debris.
Family Sminthuridae
Arrhopalites pygmaeus (Wankel) (TP)
Bartow Co.: Kingston Saltpeter Cave, 2 June 1999.
Comments: This collembolan was collected on the surface of a drip pool.
Family Tomoceridae
Tomocerus dubius Christiansen (TP)
Bartow Co.: Kingston Saltpeter Cave, 2 June 1999.
Comments: This collembolan was collected on the surface of a drip pool.
Order Diplura
Family Campodeidae
Litocampa spp. (TB)
Walker Co: Anderson Spring Cave, 1 January 1998, Fricks Cave, 11 December 1998, Spooky Cave, 19 March 1999.
Comments: Two undescribed species of *Litocampa* were collected in Walker County on cheese bait and a dead mouse.
Order Diptera
Family Calliphoridae
Calliphora vicina (Robineau-Desvoidy) (TX)
Dade Co.: Deans Pit, 15 May 1998, Howards Waterfall Cave, 16 December 1998; Walker Co.: Horseshoe Cave, 15 May 1998, 7 August 1998.
Comments: This calliphorid was collected on chicken liver in twilight and total darkness. Similar records exist from Illinois (Peck & Lewis 1977) and Alabama (Reeves, unpublished data).
Calliphora vomitoria (Linnaeus) (TX)
Dade Co.: Howards Waterfall Cave, 16 December 1998.
Comments: An adult was collected near chicken liver.
Family Cecidomyiidae
Bremia sp. (unknown) SMIT
Dade Co.: Sittons Cave, 7 August 1998.
Comments: This record represents a pale, long-legged specimen. The genus is in need of revision and specimens could not be identified to species level.
Family Chironomidae
Chironomus decorus group (TX/AC) FSCA
Washington Co.: Tennille Lime Sinks, 24 May 2000.
Comments: This fly was attracted to headlamps while in the dark area of the cave.
Procladius bellus (Loew) (TX) FSCA
Bartow Co.: Busch Cave, 2 June 1999.
Comments: This fly rests in the cave during the day.
Tanytarsus nr. *recurvatus* Brundin (TX) FSCA
Bartow Co.: Busch Cave, 2 June 1999.

Comments: This fly rests in the cave during the day.

Family Culicidae

Comments: Several species of Culicidae overwinter in caves (Makiya & Taguchi 1982).

Anopheles punctipennis (Say) (TX)

Dade Co.: Hurricane Cave, 10 December 1998, Howards Waterfall Cave, 10 December 1998; Walker Co.: Horseshoe Cave, 7 November 1998, Fricks Cave, 11 December 1998.

Culex territans Walker (TX)

Walker Co.: Horseshoe Cave, 7 November 1998.

Family Dolichopodidae

Liancalus genualis Loew (TX) UMON

Bartow Co.: Yarborough Cave, 7 September 1998.

Comments: Adults of *L. genualis* were seen on the roof and walls of the cave, probably avoiding the hot summer days outside.

Neurigonella sombria (Harmston and Knowlton) (unknown) UMON

Dade Co.: Upper Valley Cave, 10 May 1999.

Comments: This pale dolichopodid was collected on the roof in the dark zone.

Family Heleomyzidae

Aecothea specus (Aldrich) (TX)

Bartow Co. Busch Cave, 2 June 1999, Kingston Saltpeter Cave, 2 June 1999; Dade Co.: Sittons Cave, 1 October 1998.

Comments: This fly was common in Georgias caves.

Amoebaleria defessa (Osten-Sacken) (TX)

Bartow Co.: Busch Cave, 2 June 1999, Kingston Saltpeter Cave, 2 June 1999; Dade Co.: Cemetery Pit, 10 May 1999, Hurricane Cave, Howards Waterfall Cave, Rustys Cave, Sittons Cave, Upper Valley Cave, 10 May 1999; Walker Co.: Anderson Spring Cave, Ellisons Cave, 25 July 1995, Horseshoe Cave.

Comments: This fly was common in Georgia's caves.

Family Muscidae

Muscina prolapsa (Harris) (TX) OXFO

Dade Co.: Sittons Cave, 1 October 1998; Walker Co.: Horseshoe Cave, 16 August 1998.

Comments: This species has not been recorded from caves, but Holsinger and Peck (1971) reported an unidentified muscid in Yarborough Cave. *Muscina prolapsa* was always collected in total darkness.

Family Mycetophilidae

Rymosa sp. (TX/TP)

Dade Co.: Sittons Cave, 30 September 1997.

Comments: Specimens of this undetermined species were collected hanging on the webs of *Meta ovalis* near a cave entrance.

Family Phoridae

Megaselia cavernicola (Brues) (TP) LANH

Dade Co.: Howards Waterfall Cave, Johnsons Crook Cave, Newsome Gap Cave; Walker Co. Anderson Spring Cave, Pettijohns Cave, Horseshoe Cave.

Comments: *Megaselia cavernicola* larvae were collected on chicken liver, human dung, and Brie cheese.

Megaselia spelunciphila Disney (TP) LANH

Dade Co.: Deans Pit, 22 March 1998, Rock Shelter Pit, 22 March 1998; Walker Co.: Horseshoe Cave.

Comments: This species is associated with caves in Georgia and South Carolina. Reeves and Disney (1999) recently described *Megaselia spelunciphila*.

Puliciphora virginiensis Malloch (TP) LANH

Walker Co.: Horseshoe Cave, 16 August 1998.

Comments: This wingless phorid was associated with fungal hyphae and carrion.

Family Psychodidae

Psychoda pussilla Tonnoir (TP) MAXP

Walker Co.: Horseshoe Cave, 14 January 1998.

Comments: Larvae were collected on chicken liver and reared in the laboratory.

Psychoda reevesi Quate (TP) SMIT

Dade Co.: Newsome Gap Cave.

Comments: This species was collected on human dung and was recently described by Quate (2000).

Family Sciaridae

Bradysia forficulata (Bezzi) (unknown) DEIC

Dade Co.: Newsome Gap Cave, 29 May 1998.

Comments: A single female was collected from organic debris. Several species of *Bradysia* are troglophiles in Mexico (Reddell 1981), but the status of Nearctic species is not fully known.

Corynoptera sp. (unknown) DEIC

Dade Co.: Upper Valley Cave, 10 May 1999. Walker Co.: Horseshoe Cave, 30 May 1998.

Comments: Female *Corynoptera* were collected from organic debris.

Lycoriella sp. (TP) DEIC

Bartow Co.: Anthonys Cave, 20 May 1999. Dade Co.: Deans Pit, 22 March 1998, Newsome Gap Cave, 29 May 1998; Walker Co.: Pettijohns Cave, 3 August 1998, Horseshoe Cave, 30 May 1998, 30 September 1998.

Comments: These records represent an undescribed cavernicolous species.

Family Simuliidae

Prosimulium saltus Stone and Jamback (TX)

Dade Co.: Newsome Gap Cave, March-April 1998.

Comments: Larvae and pupae were recorded from this cave (Reeves & Paysen 1999).

Simulium parnassum Malloch (TX)

Dade Co.: Newsome Gap Cave, March-June 1998.

Comments: Larvae and pupae were recorded from this cave (Reeves & Paysen 1999).

Family Sphaeroceridae

Leptocera caenosa (Aldrich) (TP)

Dade Co.: Newsome Gap Cave, 29 May 1998; Walker Co.: Pettijohns Cave, 3 August 1998.

Comments: This fly was common in caves on carrion, cheese, and dung.

Spelobia tenebrarum (Aldrich) (TB)

Chattooga Co.: Blowing Springs Cave; Dade Co. Howards Waterfall Cave, Rising Fawn Cave, Johnsons Crook Cave; Walker Co.: Mt. Cove Farm Cave, Pettijohns Cave, Bible Spring Cave.

Comments: Marshall and Peck (1984, 1985) reported these records. They assume *S. tenebrarum* is a troglobitic species because of its reduced eyes, cave-restricted range, and lack of active flight.

Family Syrphidae

Copestylum vesicularium (Curran) (TX) SMIT

Grady Co.: Maloys Waterfall Cave, 6 March 1999.

Comments: Adults probably overwinter in the cave.

Family Tipulidae

Dolichopeza tridenticulata Alexander (TX) CARN

Dade Co.: Sittons Cave, 7 August 1998.

Comments: This species of crane fly was found only during the late summer.

Dolichopeza walleyi (Alexander) (TX) CARN

Bartow Co.: Anthonys Cave, 20 May 1999.

Comments: This crane fly hangs from the roof of the cave during the day.

Tipula abdominalis (Say) (TX)

Walker Co.: Ellisons Cave, 29 July 1995.

Comments: A larva was collected near the "Historic Entrance".

Family Trichoceridae

Trichocera fattigiana Alexander (TX) CARN

Dade Co.: Hurricane Cave, 10 December 1998, Howards Waterfall Cave, 10 December 1998; Walker Co.: Anderson Spring Cave, 1 January 1999.

Comments: This winter crane fly was common near the entrances of caves.

Trichocera sp. (TX) CARN

Dade Co.: Howards Waterfall Cave, 16 December 1998; Walker Co.: Horseshoe Cave, 14 February 1998.

Comments: In Horseshoe Cave, a female was entangled in a carrion trap. Species identification was not possible due to the gender.

Order Hemiptera

Family Cicadidae

Magicicada sp. (ED)

Walker Co.: Horseshoe Cave, March 1998.

Comments: This periodic cicada is a true edaphic species, but some immatures become trapped in caves prior to emergence.

Family Veliidae

Microvelia americana (Uhler) (AC) SMIT

Dade Co.: Howards Waterfall Cave, 10 December 1998.

Comments: An individual was collected in a cave pool.

Order Hymenoptera

Family Braconidae

Aspilota spp. (TP)

Dade Co.: Sittons Cave, 1 October 1998, Deans Pit, 22 March 1998, Rock Shelter Pit, 22 March 1998, Upper Valley Cave, 10 May 1999.

Comments: These braconids were parasitoids of immature phorids. Braconids emerged individually from phorid puparia (Reeves & Disney 1999). Adults were observed on cave walls, carrion, and cheese.

Family Formicidae

Myrmecina americana Emery (TX)

Dade Co.: Newsome Gap Cave, 29 May 1998.

Comments: This ant was foraging in the dark zone.

Order Lepidoptera

Family Noctuidae

Scoliopteryx libatrix (Linnaeus) (TX)

Dade Co.: Johnsons Crook Cave, 20 December 1998, Howards Waterfall, 10 December 1998, Newsome Gap Cave, 29 May 1998; Walker Co.: Horseshoe Cave.

Comments: *Scoliopteryx libatrix* uses caves as hibernacula and has a world-wide distribution (Peck & Lewis 1977).

Order Odonata

Family Cordulegastridae

Cordulegaster sp. (TX)

Washington Co.: Tennille Lime Sinks, 24 May 2000.

Comments: These sand dwelling odonates were common in the Tennille Lime Sinks stream.

Family Gomphidae

Progomphus obscurus (Rambur) (TX)

Washington Co.: Tennille Lime Sinks, 24 May 2000.

Comments: These sand dwelling odonates were common in the Tennille Lime Sinks stream.

Order Psocoptera

Family Liposcelididae

Liposcelis decolor Pearman (TP)

Bartow Co.: Kingston Saltpeter Cave, 2 June 1999; Walker Co.: Ellisons Cave, 29 July 1995.

Comments: *Liposcelis decolor* was collected in bat guano and in debris.

Order Siphonaptera

Family Ctenophthalmidae

Ctenophthalmus pseudagyrtes Baker (SY) GASO

Walker Co: Pettijohns Cave

Comments: Two adult *Ctenophthalmus pseudagyrtes* were collected in the cave. These fleas usually feed on small mammals.

Order Trichoptera

Family Hydropsychidae

Diplectrona marianae Reeves (TX**)**

Dade Co. Newsome Gap Cave, March-April 1998, 29 May 1998.

Comments: Adults and larvae of this species were collected from a cave stream and surrounding passages (Reeves & Paysen 1999).

DISCUSSION

Updated local checklists are essential for protecting cave organisms. Holsinger and Peck (1971) presented an annotated checklist of cave fauna in Georgia, but many caves and microhabitats were omitted. Our work indicates further research is needed in caves where undescribed or unidentifiable species were collected. These species include most of the nematodes and fungi, which are seldom-reported in checklists. Future research into the life history and taxonomy of cavernicolous fungi and worms could reveal undetected troglobitic species.

The majority of the species found in Georgia's caves were not unique to the state and can be found in caves of Alabama, Florida, North Carolina, South Carolina, and Tennessee. The five zoogeographic patterns presented by Holsinger and Peck (1971) can be partially supported by our data. Their first pattern, which states that some troglobitic species are common in the southern Appalachians, was supported. However, this statement is ambiguous and further sampling and taxonomic revisions will probably indicate that the true ranges of these troglobites are restricted by geologic or historic factors. Our data support the hypothesis that many aquatic species inhabit the phreatic zone and, thus, enter connected phreatic cave systems. For example the amphipod *Crangonyx antennatus* was collected in different drainage basins and was reported to be in caves throughout the southern Appalachians (Holsinger & Peck 1971).

Their second pattern, which stated that some species are limited to the plateau caves, was also supported by our additional records. For example the millipede *Pseudotremia eburnea* was found in the caves of Lookout Mountain and Pigeon Mountain but it was not collected in any of the valley caves of Walker or Bartow Counties. Another troglobitic millipede *Scoterpes austrinus* shared some of its distribution range with *Pseudotremia eburnea*, but *Scoterpes austrinus* was also collected in the valley caves of Bartow County.

Their third zoogeographic pattern, which states that some species are limited to karst subunits, was supported by our data. This pattern was an extension of the second pattern, but further limits karst regions within the plateaus and valleys. An example of this pattern was demonstrated by the records of both *Ptomaphagus* beetle species, which were restricted to Lookout Valley and the flanks of Pigeon Mountain.

Their fourth and fifth patterns were problematic. It stated that two species, *Pseudanophtalmus fulleri* and *Apochthonius minor,* were found in both the plateau and valleys. Extensive collections have not been made of either species, and we do not have evidence to refute this pattern. The apparent pattern could be an artifact of small sample sizes. The same problem exists for their fifth pattern, which states that only two species of *Stygobromus* are known exclusively from the Appalachian Valley. There is no evidence this was untrue, but extensive samples in the phreatic region have not been made.

There are three major limitations in understanding the zoogeography of troglobitic and troglophilic species in Georgia. First, the general life histories and habitat requirements of almost all cavernicoles are unknown. Ecological factors influence the distribution of all species, and research is needed to determine what factors are important for cavernicoles. The second limitation in understanding Georgia's cave fauna is the lack of information on the fauna of Coastal Plain caves. Some coastal regions of the state are biologically unsurveyed. Finally the dwindling taxonomic community makes identification of some cavernicoles impossible.

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EYED CAVE FISH IN A KARST WINDOW

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Caballo Moro, a karst window cave in northeastern Mexico, supports a mixed population of cave Astyanax mexicanus*: eyed and eyeless. The relationships of these sub-populations to one another and to other populations of Mexican tetras were examined using RAPD DNA fingerprint markers. The eyed tetras of Caballo Moro Cave are genetically closer to blind tetras from Caballo Moro and other caves in the region than they are to eyed tetras from the surface. The two forms are not genetically identical, however, and may represent distinct sub-populations.*

Eyed and eyeless fish have a distributional bias in the cave, with eyed fish preferentially in the illuminated area and blind fish in the dark zone. Aggression of eyed towards blind fish in the illuminated area contributes to this bias and may serve to stabilize the eye-state polymorphism.

We considered four hypotheses for the origin of Caballo Moro eyed cave fish. The RAPD data rule out that the mixed population represents a transitional stage of evolution, or that the eyed fish are unmodified surface immigrants. We cannot rule out that the eyed fish are the direct descendants of surface fish that have acquired markers from blind fish by hybridization, although the apparent distinctness of the two sub-populations suggests otherwise. An alternative hypothesis, that the eyed fish of the cave are direct descendants of blind cave fish that re-acquired eyes with the opening of the karst window, is consistent with the data and tentatively accepted.

The Mexican Tetra, *Astyanax mexicanus*, is a visually orienting, schooling fish widely distributed in surface streams of northern Mexico. In addition to the epigean populations, numerous cave forms of this species occur in the Sierra de El Abra region of northeast Mexico (Fig. 1; Mitchell *et al.* 1977). In contrast to the surface fish, these troglobitic forms have rudimentary, non-functional eyes, and their melanin pigmentation is reduced or absent.

Generally, caves with troglobitic Mexican tetras do not contain eyed tetras, except for the occasional doomed individual swept underground. One exception is El Sótano de El Caballo Moro, which contains an apparently stable, mixed population of *A. mexicanus*, both eyed and eyeless.

The entrance of Caballo Moro Cave (CMC) is a karst window. Karst windows are habitats within cave systems that are exposed to light, and typically result from cave passage collapse. The 50-m deep entrance pit of CMC is found at the bottom of a 60-m doline, and leads directly to a large "lake" of approximately 18 m x 90 m. (Cave "lake" in this case, is a wide stream pool). Light reaches only the upstream half of the lake, while the downstream half remains in darkness. The lake contains both blind depigmented and eyed pigmented forms of *A. mexicanus*. The distribution of fish in the lake appears to be biased, with over-representations of blind fish in the dark area and eyed fish in the light area.

Mitchell *et al.* (1977) observed that the source of the eyed fish of Caballo Moro cave was a mystery. The cave's entrance pit is 11 km away from the nearest potential resurgence and does not capture a surface stream. Furthermore, there is no permanent water nearby. The nearest recorded surface fish locality in the Río Boquillas system is 4 km distant. They hypothesized that seasonal flooding of Río Boquillas tributaries affords occasional access to the cave through, as yet undetected, sinks.

As part of a larger study of the evolutionary history of the Mexican cave tetra, we investigated the relationships of the eyed fish of CMC. If they represent an unmodified surface population recently captured from a nearby sink, their presence in the karst window would be unremarkable. If, on the other hand, the population were of long standing, it would raise the question of the maintenance of its integrity in the face of potential hybridization with, and introgression of genes from, the troglobites. Alternatively, if the eyed fish of the cave originated from blind cave progenitors, they would make a good model for study of the effects of the reversal of selection pressures on populations.

MATERIALS AND METHODS

The relationships among representative surface and cave populations of *Astyanax mexicanus* from the El Abra region were studied using RAPD data. RAPD (synonymous with AP-PCR) technique generates a DNA fingerprint from genomic DNA using the polymerase chain reaction (Welsh & McClelland 1990; Williams *et al.* 1990). RAPD fingerprints are species and population specific and carry significant amounts of taxonomic information (Borowsky *et al.* 1995).

The following populations were sampled (Fig. 1): caves: Molino, Vasquez, and Caballo Moro: surface: Río Frío, Río

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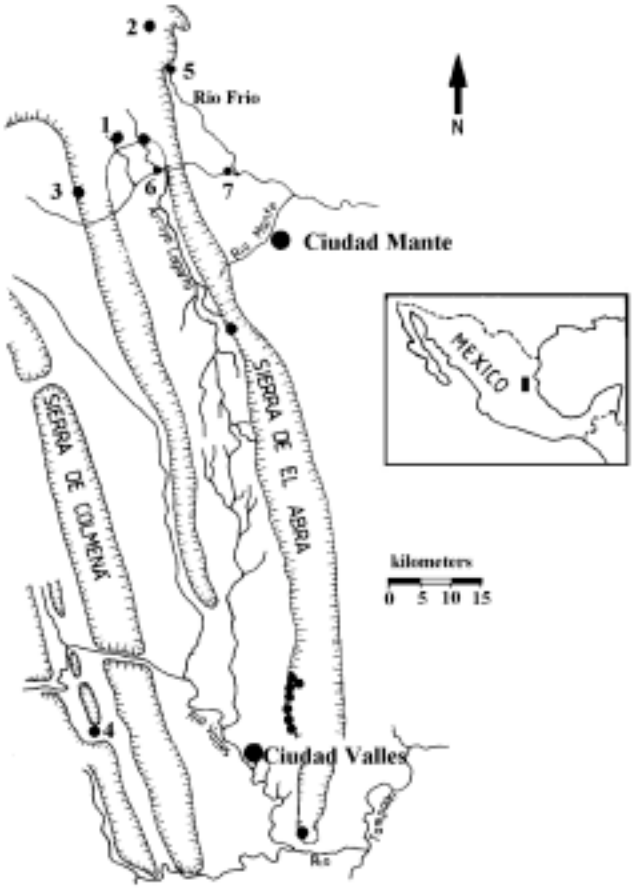


Figure 1. Map of the Sierra de El Abra region showing the collection sites. 1) Caballo Moro cave, 2) Molino cave, 3) Vasquez cave, 4) Río Subterraneo cave (a "Micos" cave), 5) the Río Frío surface locality at the Nacimiento de la Florida, 6) a surface locality in the Río Boquillas system, 1 km upstream of La Servilleta canyon, and 7) the Río Comandante surface locality, just upstream from its confluence with the Río Frío . Other caves in the area are shown as unlabeled solid circles. (Redrawn from Wilkens 1988.)

Boquillas and Río Comandante. *Astyanax aeneus* from the Río Granadas, a tributary to the Río Amacuzac, northeast of Taxco, Guerrero, Mexico, were used as the outgroup for phylogenetic analyses. Two individuals each were examined from Molino cave, Vasquez cave, all surface localities, and *A. aeneus*. Five blind individuals and six eyed individuals were examined from CMC. RAPD amplification procedures followed Borowsky *et al.* (1995). Two primers were used: Mey7 (5'ggagtaggggatatgatcgatgga3') and Mey8 (5'cagcaaacagaaaccagtcag3'). Reactions were cycled five times in a Hybaid thermocycler: 94°C for 70 s, 40°C for 5 minutes, and 72°C for 3 minutes, followed by 35 cycles at higher stringency: 94°C for 70 s, 50°C for 1 minute, and 72°C for 90 s. Reaction products were run on 6% polyacrylamide gels (29:1) and silver stained (after Gottlieb & Chavko 1987). RAPD fragment distributions were compared among individuals using a size match criterion. Each uniquely sized band was assumed to be a character, and character states were scored as "present" or "absent."

Phylogenetic analysis of the data was done using Paup 4.0b2 software (Swofford 1999). Maximum parsimony analysis (character states unordered) was done by bootstrapping the data (1000 replicates) using full heuristic search to produce a 50% majority-rule consensus tree. For analysis of distance ("mean character difference"), neighbor-joining trees were generated from bootstrapped data (1000 replicates) and used to obtain a 50% majority-rule consensus tree.

A supplementary analysis was done using a Monte Carlo procedure to estimate the variance of distances among individuals within and between the sets of eyed and eyeless fish from CMC. Individual phenotypes for distance comparisons were created by sampling, based on the frequencies of bands in each set. Twenty such pairs of phenotypes were generated for each simulation and the calculated distances were used to estimate means and their standard deviations. For this analysis, distances were calculated as the sum of the absolute differences in band frequencies among taxa or individuals divided by the number of bands.

RESULTS

One hundred and fifty-eight bands were scored, of which 127 were variable and of value in distance analysis, and 58 were parsimony informative. The number of bands observed in any individual ranged from 55-69. The raw data matrix presented as table 1, is organized in the style of a "sequence alignment." As such, it arrays the character states of the outgroup species along the top row (+, -, and "P" for polymorphic). The character states for the other taxa are arrayed below, using "." to denote state identity with the outgroup, and the other symbols, where different from the outgroup. The data were sorted by character states in the cave fish, putting "-" towards the left and "+" towards the right. This arrangement makes apparent a series of derived bands shared among all cave fishes or among all individuals of Caballo Moro cave. These synapomorphies imply a closer relationship of the eyed fish of Caballo Moro cave to other cave fish than to epigean fish.

This implication is supported by both parsimony and distance analyses, which gave essentially the same result: consensus trees with two clusters, one consisting of the epigean populations and the other of the cave populations. The tree produced by distance analysis (Fig. 2) had a little more structure than the one based on parsimony and may be more appropriate for analysis of populations that can hybridize. The relationship of the eyed and blind fish of Caballo Moro cave is strongly supported by a bootstrap value of 0.83 as is the clustering of all fish of Caballo Moro cave with the other cave fish (bootstrap value of 0.82). The tree also shows a clustering of four of the five blind fish within Caballo Moro, which suggests that the eyed and blind fish of the cave may comprise two distinct sub-

Table 1. Character states for the 127 variable RAPD bands. The top line gives the states in the *Astyanax aeneus* outgroup: "+" = band present, "-" = band absent, "P" = population polymorphic. Character states for the other groups are aligned below those of the outgroup. The symbol "." denotes a state identical to that in the outgroup. Characters were sorted from left to right, putting characters with "-" states in cave fish first.

```
Outgroup   ---PP++----P--+-+++--++-+-----++++---++--+++-+---++---+-P-+-PP+-+++---+-+--+-+--+-+--+-------------P+P-+-+-++-P--+P-+---+++PP+P

Boquilla   ...----....-..-.---..--.-....----PPP--+.-P-P-P+PP.P....-+.+++-.P-.+++...+...-+..+.P..+.P.+P....PP+-P..-+-+-P++++.++-+++.P.++.+
Comandan   .P.----....-.P-.---..--.+...-----...P-.+---.P++.P-+P.-..+-.++-.---.+++.+.+....+..+.P..+...+.......P-.-P-+-P.-+-++.++.+++...++P+
FloridaR   P..----.....+P-.---.+--.....+---...--.+---P.+P+.-PP.-.+P.P++-.---.+.+.+.+...-+P.+.P..+...+P....++.-P-PPPP+-P+.++..+.+++.P.++.+

MoroBl01   ...----....-..-.---..--.-....----...--.---.-...--+..-.-.-.---.---+...+.+..+-+..+.+.-++++++++++++++.++.+.+..++++.++.+++...++.-
MoroBl02   ...----....-..-.---..--....+.----...--.---.-...---..-+-.-+---.---...-+.++.+.++-+-++-++++++++++++++.++.+.+..++++.++.+++...++.+
MoroBl03   ...----....-..-.---..--.-....----...--.---.-...-...-.-.-.---.---...-+-++-...+-+-++-.++++++++++++.++.+.+..++++.++.+++...++.+
MoroBl04   ...----....-..-.---..--.-....----...--.---.-...-...-.-.-.---+-.---.-+-++-+.++.+-++-.++++++++++++.++.+.+..++++.++.+++...++.+
MoroBl05   ...----....-..-.---..--.-....----...--.---.-...-...-.-.-.---.---...-+-+.-+..+-+.++-.++++++++++++.++.+.+..++++.++.+++...++.+
MoroEy01   ...----....-..-.---..--.-....----...--.---.-...--.+.-+-.-.---.---.++.-.+...-.+-+.++.+++.++++++++++.++.+.+..++++.++.+++...++.-

MoroEy02   ...----....-..-.---..--.-....----...--.---.-...--...-.-.-.---.---++.......+-+.....+.++++++++++++.++.+.+..++++.++.+++...++.+
MoroEy03   ...----....-..-.---..--.-....----...--.---+-...--..+-.-.-.---.+.--.++-.-.....-++......++++.+++++++++.++.+.+..++++.++.+++...++.+
MoroEy04   ...----....-..-.---..--..+..----+...---.---.-...---.-.-.---+---..+-.-.+-.-+-.-++.++++++++++++++.++.+.+..++++.++.+++...++.+
MoroEy05   ...----....-..-.---..--.-....----...--.---.-...--.+.-.-.---+---...-.-.-.-.+...+.++++++++++++++.++.+.+..++++.++.+++...++.+
MoroEy06   ...----....-..-.---..--.-....-----..+--.---.-...---.-+-.-.---.-.---.-.+-+-.+..-++.++++++++++++++.++.+.+..++++.++.+++-..++.+

MolinoCa   ...---+.++-..-+---.--.-....-----.+.--+.-P-.-..+-.+.+.+-P-+---.---.+.+-++.+.+.-+-.+.++.+..++++++++-++.......+++-++.+++...++.+
VasquezC   ..P----.+..-..-.---+.--+-+....----...-...-..-...-----.-.-.--.-----------.+.+.+.-+-+.P+.++++++++...+-++.+.+..++.+.++.+++..-++.+
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populations, in spite of their closeness.

The supplemental distance analysis lends some support to these hypotheses. Distances calculated among populations showed the eyed and eyeless fish of CMC to be closer to each other (0.101) than either was to surface fish (0.337 and 0.359, respectively) or to the other blind cave fish (0.253 and 0.240, respectively). The distance between the eyed and eyeless fish of CMC was investigated in more detail by Monte Carlo simulation. The average distance between simulated eyed and eyeless individuals (0.095 $\pm$ 0.015) was significantly greater than the average distance between simulated eyed individuals (0.067 $\pm$ 0.016, $t_{38} = 3.83$, $p < 0.05$) or simulated eyeless individuals (0.031 $\pm$ 0.012, $t_{38} = 9.60$, $p < 0.05$). The means and standard deviations of all the distances measured among the real individuals in the two groups are very similar to those in the simulation (between sets: 0.1226 $\pm$ 0.0264; eyed: 0.0965 $\pm$ 0.0215; eyeless: 0.0513 $\pm$ 0.168) and the t values are high ($t_{38} = 9.60$ and $t_{43} = 3.24$), but only the t tests in the simulation are valid.

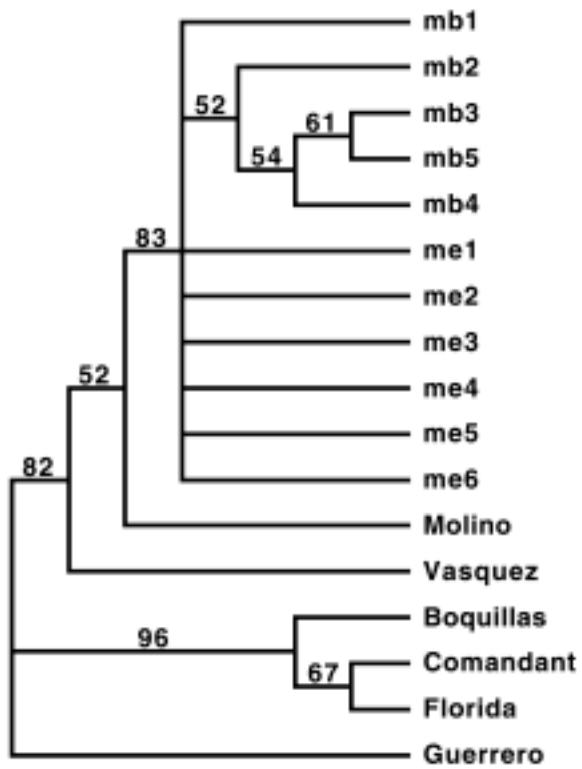


Figure 2. Bootstrapped Neighbor-Joining tree showing the relationships among cave and surface populations of *Astyanax mexicanus*. Figures on branches are the percentage of bootstrapped trees that had identical clusters and measure the reliability of the associations. The Guerrero population of *Astyanax anaeus* served as outgroup in the parsimony analyses.

Of 41 fish collected from Caballo Moro Cave, 21 were eyed and pigmented, and eighteen had eye rudiments completely covered by muscle and scales and were depigmented. Two were intermediate in phenotype. The collection made from the dark side of the lake had eight fish, one with eyes. The collection made from the illuminated side of the lake had seventeen fish, ten with eyes (locations of other specimens had not been recorded). The biased distribution is statistically significant (Fisher's exact test, $p < 0.05$). We observed eyed fish nipping and chasing blind fish on the illuminated side, and this behavior may contribute to the distributional bias within the lake.

DISCUSSION

At least four hypotheses could account for the presence of eyed fish in Caballo Moro cave. The first is that the eyed individuals are surface fish recently swept underground. As such, their residency might be short-lived and they would not necessarily be part of the troglobitic population. A second hypothe-

sis is that the eyed fish represent one phenotypic extreme of a variable cave fish population in evolutionary transition towards eyelessness. A third is that they are the descendants of surface fish swept underground that had interbred with the blind fish and acquired their RAPD marker set by hybridization. A fourth is that the eyed fish are descendants of blind, depigmented cave fish that reacquired eyes and pigmentation through an evolutionary process. The reacquisition of eyes and pigment in troglobites reintroduced to light has been suggested before, for karst window populations of the amphipod *Gammarus minus* (Culver *et al*. 1995).

We reject the first hypothesis because it predicts that the eyed fish of CMC should be genetically closer to surface fish than to the blind cave fish. Our results showed the opposite to be true; both distance and parsimony analyses clustered the eyed fish of the cave with blind cave fish rather than surface fish. This clustering was well supported by bootstrap analysis (Fig. 2).

What of the second hypothesis? Is the CMC population in transition from an eyed to a blind condition? Wilkens (1988) hypothesized such a situation in the isolated cave populations of the Micos area, to the west of the El Abra. Micos fish have reduced eyes, but the rudiments are better developed than in the cave tetras of the Sierra de El Abra region, and Micos fish are not fully depigmented. Wilkens suggested that the Micos cave tetras are in transition because they are "phylogenetically younger" than other populations of troglobitic Mexican Tetras, and our (unpublished) RAPD data support this contention.

Nevertheless, we think it unlikely that the CMC population is in transition between the eyed and blind conditions, as in the Micos fish. First, Caballo Moro cave is centrally located within the range of other populations of cave tetras, none of which appear to be in a transitional state. Second, the fish of the Micos caves are uniformly intermediate in eye size and pigmentation phenotype according to Wilkens (1988) and our unpublished observations, while most (95%) of the Caballo Moro cave fish fall into two distinct morphological groups — eyes functional *versus* blind. Thus, any intermediate "transitional" quality of the CMC population exists primarily as a statistical average of two phenotypic extremes.

We cannot yet distinguish between the third and fourth hypotheses: the eyed fish of the cave may have descended from a captured surface population having interbred extensively with the blind fish or it may have descended from blind cave ancestors by reacquisition of eyes and pigment. Both hypotheses predict extensive sharing of character states among eyed and eyeless fish from CMC and might prove difficult to distinguish in practice.

A test based on distance data may be possible. Our results show that the average distance between eyed and eyeless individuals of CMC is significantly greater than the average distances within these sets. A biologically significant genetic distance between the two groups of fish would arise in different ways according to the two hypotheses. Hypothesis three is one of introgressive hybridization, and would view distance as evidence of a mixing process not yet complete. Hypothesis four is one of centripetal evolution and would view distance as a derived state, as one subset splits from the other. Thus, hypothesis three predicts the eyed fish of CMC to be closer than their eyeless companions to the fish of the surface and more distant from the fish of the other caves. Instead, our data show both groups in CMC to be equally far from surface fish and equally far from the other cave fish. Thus, the current data support hypothesis four, but more will be necessary for a definitive test.

The data presented here confirm the status of the CMC population as one worth further study for the light it can shed upon evolutionary processes. Karst windows, in general, should provide unique opportunities to study the effects of the alteration of selective pressures on troglobites and the ecological and evolutionary interactions between troglobitic and surface species.

ACKNOWLEDGMENTS

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DISCUSSION: "DISTRIBUTION MAP OF CAVES AND CAVE ANIMALS IN THE UNITED STATES"

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Culver *et al.* (1999) counted numbers of caves (C) and of obligate cave-dwelling organisms (S) in each of 1144 counties in the United States with known caves, and presented distributions maps and a scatter plot (their figure 3) of S *versus* C. They used the latter to display a linear regression in the form $S = a + bC$, and conducted tests of the null hypotheses $a = 0$ and $b = 0$. They used the standard Student t tests of these hypotheses and, rejecting them, asserted a positive correlation between S and C. Although there may indeed be a significant correlation between S and C, their data do not satisfy the conditions for applying the t test. These are:

1) There must be a justification for assuming the expected value of S is linear in C, but the hypothesis is not tested.
2) The variable S must be (at least approximately) normally distributed about its expected value, and the variance of S must be independent of C (homoscedastic). It is apparent from inspecting figure 3 that neither of these is true.
3) There must be insignificant variance of the variable C within counties, compared to that of the variable S. However, C is only a small fraction of the total number of proper caves in any region, and it has been shown that a stochastic process leads to most caves losing all proper entrances in such a way that the variance of the number of proper caves with proper entrances is large (Curl 1966).
4) Cave organisms do not restrict themselves to proper caves. There is a much larger number of non-proper caves, caves too small for human entry, than of proper caves (Curl 1986). The value of C, therefore, is not only an indirect but also an imprecise measure of the subterranean habitat accessible to cave organisms.

Since too little is known about the variables S and C and their relationship, including what both the functional form and statistical distributions are, a non-parametric, distribution-free test of statistical independence is required. I applied a 2x2 contingency test to data shown in figure 3, with levels defined as $[0 < S \leq 12, 12 < S]$ and $[0 < C \leq 150, 150 < C]$, and obtained the test statistic $\chi_1^2 = 102$, with one degree of freedom. This is significant at less than the 0.1 % level, and the null hypothesis of statistical independence of S and C is rejected at that level. This test emphasizes the cited upper levels of S and C, which constitute only 8 % of the data.

There are possible sources of statistical dependence that may or may not be related to causations of ecological interest, in the form of common variables affecting both S and C. The area of counties may be one such variable. The number of caves observed in a karst region would increase with the area of the region and one might expect the number of observed species to increase, also. This common-mode effect might be suppressed by dividing each S and C pair by the area of karst in that county. Another common variable, but of ecological significance, might be climate. Karst areas with heavier precipitation might simultaneously have more cave development and be biologically richer than more arid areas.

In summary, while a linear regression t test and a contingency test arrive at the same conclusion that S and C are statistically dependent, the several assumptions inherent in linear regression are not supported. The relationship between S and C, and these to other variables that may be common sources of the statistical dependence observed, need to be elucidated, especially to identify ecological processes and parameters that relate S to C. I look forward to these considerations being addressed with the authors' promised more complete analysis of their data.

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REPLY: DISTRIBUTION MAP OF CAVES AND CAVE ANIMALS IN THE UNITED STATES

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First, we would first like to thank Professor Curl for his comments and interest in our recent work on the geographic distributions of caves and subterranean fauna in the coterminous United States (Culver *et al*. 1999). We welcome the opportunity to discuss and clarify some of the statements made in our manuscript.

Each comment of Professor Curl's is addressed in turn. We wish to emphasize that any statistical analysis presented in the paper was solely exploratory in nature in order to provide some initial confirmation for the conclusion of similar spatial distributions for the caves and cave species (Figs. 1 & 2).

1) We did not test whether the relationship between S (number of species) and C (number of caves) was linear for two reasons.

a) The emphasis in this paper was on demonstrating graphically that a relationship (linear or otherwise) exists between S and C. That can be seen quite clearly in figure 3, which also shows that for large numbers of caves the relationship is at least approximately linear.

b) A lack of fit test at this stage of the analysis would have been inappropriate since no detailed study had yet been performed. Such a test would be part of a more detailed, not exploratory, analysis.

2) Curl is certainly correct in stating that the variance of S is increasing in C. Constant variance and a normal distribution for the response variable are the usual assumptions for testing in linear regression. We agree that a full analysis would certainly account for failure of the data to meet these assumptions. We did cite the t-statistics and their p-values without noting the failure of these assumptions for these data but we wish to point out the following:

a) The assumption of normality can be relaxed somewhat since i) the t-test is quite robust to the failure of this assumption and ii) the sample size is so large that the estimates of the model coefficients are likely normally distributed anyway (they are weighted averages of the response variable and hence the Central Limit Theorem can be applied).

b) In general, the failure to account for heteroscedastic variance has the unintended consequence of overestimating the variance that is assumed to be constant (Draper & Smith 1967). As a result of the overestimation, the t-test is conservative and is less likely to support the conclusion of a relationship unless that relationship is quite strong.

3) The assumption of no measurement error in C, the number of caves in a county, is certainly violated here for many reasons, including those mentioned by Professor Curl. Unfortunately, there is literally no means by which we might assess the magnitude of the measurement error based on the available data. The only alternative is to make some strong assumptions about the error associated with the number of caves per county for every single county in the United States. That, itself, would introduce an additional source of error to the analysis so that any inferences would be dependent on the validity of these additional assumptions. Instead we recognize that the number of observed caves in a county is a surrogate measure for the more important but unobservable variable that might be called habitat availability.

A more suitable measure might be the total length (or volume) available in a county, but this in turn would require, in addition to a complete enumeration of cave lengths (and volumes), an estimate of the fractal dimension of the karst. Curl has, of course, pioneered in this area (Curl 1966, 1988), but there are simply not data available at the scale needed. It is worth pointing out that if the fractal dimension is more or less constant, then an estimate of habitat by number of caves may be relatively robust.

4) We are pleased that the contingency table analysis performed by Professor Curl supports our own preliminary conclusions that the number of species and the number of caves are related. The advantage of the 2x2 test is that it relies less on assumptions than the test of the slope of a linear regression. There are also disadvantages such as being unable to infer the direction of the relationship of the two variables without further analysis and the dependence of the test on the researcher's choice of the levels or categories for analysis.

5) Professor Curl implies that the observed relationship may be due to a latent variable, county area, which influences both S and C. Neither the number of caves nor the number of species in a county is correlated with the size of the county for those counties in which at least one species has been reported (r = - 0.064 for S and Area and r = - 0.017 for C and Area). Hence, the relationship is not due to the potentially latent effects of area.

Professor Curl rightly points out that many other variables may be as or more important than the number of caves for explaining the distribution of the number of cave species in the United States. There is no doubt that a complete analysis would include such information as climatic variables, vegetative cover, and many other potential explanatory variables, if data were available. As a first step, we recently completed a more detailed account of the relationship between cave numbers and species counts for the southeastern region of the United States (Christman & Culver in review). We show that, based on the available data, the relationship between S and C is best described as a log-log function, with different functions for different karst regions. We further show that there is spatial dependence in the dataset. Even after the effect of the number of caves is accounted for, there is unexplained variability in the number of species that can be explained in part by the species density in neighboring counties. This suggests that species have migrated in subsurface routes between counties or have been influenced similarly by unmeasured factors such as the Pleistocene ice sheet boundary.

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SELECTED ABSTRACTS FROM THE 2000 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN ELKINS, WEST VIRGINIA

ARCHAEOLOGY

PREHISTORIC CAVE ART IN WEST VIRGINIA

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An array of petroglyphs, almost certainly of prehistoric origin, is described from an unnamed cave ("14th Unnamed Cave") in West Virginia. At least 22 individual glyphs are arrayed in a single panel located in the twilight zone, near the cave opening. The images are all abstract designs, with no recognizable representations. Archaeological materials in the cave include Late Woodland ceramics, suggesting that these works are contemporary with cave art to the east in Virginia and to the south in Tennessee.

ARNOLD CAVE: A DARK-ZONE PICTOGRAPH SITE IN WISCONSIN'S UNGLACIATED "DRIFTLESS AREA"

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Arnold Cave is an interstratal cave within the St. Peters Sandstone, which is exposed within the unglaciated Driftless Area of southwestern Wisconsin. The cave is located near a ridgetop, and consists of three interconnected chambers that extend ~100 m.. Natural light penetrates only the first 7 m of the first room. Prehistoric charcoal drawings are in each of the rooms, many in the dark zone. Arranged in 6 panels, images include humans, birds, deer, and abstract geometric forms. One glyph was AMS dated to ca. 1200 BP, corresponding to the Late Woodland Effigy Mound Culture in this region. The cave floor is littered with birch bark torches and the sole of a hide moccasin was recovered from the surface of the second room. An AMS date on the moccasin is ca. 500 BP. To date, efforts have focused on mapping the cave, recording the rock art, and constructing a gate.

EL ARTE RUPESTRE EN EL CENTRO DE CUBA (ROCK ART IN SANCTI SPIRITUS, CUBA)

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Nos propusimos estudiar varias localidades con arte rupestre en la provincia de Sancti Spíritus, que incluyen las cuevas de la costa norte, Punta Judas y Guayarúa, los cayos Caguanes, Salinas y Lucas, los Farallones de la Virtud en Banao y la Cueva de María Teresa o La Jía del municipio de Trinidad. Se exponen además los aportes de diferentes investigadores cubanos. Diremos como nuestro maestro el doctor Antonio Nuñez Jiménez que las cuevas son "pétreos cofres" donde han quedado preservadas las huellas del pasado. Analizamos los pictogramas y petroglifos por medios estadísticos, descriptivos y de comparación con otros países como Bahamas, Puerto Rico y Perú para poder establecer vínculos migratorios entre las culturas precolombinas que habitaron esta región. Expondremos otros elementos de los petroglifos y pictografías como la distancia en que se ubican de la luz natural, si están en oscuridad total y a que altura del suelo se encuentran, entre otros.

We have studied rock art localities in the province of Sancti Spiritus, including caves on the north coast, Punta Judas and Guayarua, the Caguanes, Salinas and Lucas Keys, the Farallones de Virtud in Banao, and Cueva de Maria Teresa or La Jia in the municipality of Trinidad. We reviewed the contributions of different Cuban researchers. We think, like our teacher Dr. Antonio Nunez Jimenez, that the caves are "stone coffers" preserving remains of the past. We analyzed the pictograms and pictographs through statistics, descriptions and comparisons with those of other localities such as the Bahamas, Puerto Rico, and Peru to address the issue of migration among pre-Columbian cultures of this region. We analyze the pictograms and petroglyphs through statistics and discuss other aspects of the petroglyphs and pictographs, such as distance from natural light, occurrence in the dark zone, and height above the cave floor.

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THE STRATIGRAPHY OF DUST CAVE AND BASKET CAVE IN THE CONTEXT OF THE MIDDLE TENNESSEE RIVER VALLEY

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Dust Cave in the Middle Tennessee River valley of Northern Alabama contains a uniquely well preserved chronosequence that includes 5 distinct cultural components dating from the Late Paleoindian (10,500 BP) through the Middle Archaic (5200 BP).

THE ART AND ARCHAEOLOGY OF 12TH UNNAMED CAVE, TENNESSEE

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The first cave art site ever recognized in the Southeast of North America, 12th Unnamed Cave, is also one of the most elaborate. Hundreds of petroglyphs and one ceiling panel of mud glyphs are scattered through the cave's twilight and dark zones. Among these are human effigies, avian images, mythological beings, and a variety of abstract designs. Several panels clearly represent intentional groupings of images into compositions that depict real or mythic "events", and there seems to be an overall plan guiding image placement through the cave as a whole. Cave topography may have had a role in artistic composition. Several episodes of cave use are indicated in remnant intact sediment profiles. Radiocarbon dates and associated artifacts indicate that the cave was used during the Woodland period but saw its most intensive use during the late prehistoric Mississippian period.

ABORIGINAL GLYPH CAVES IN ALABAMA

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Four glyph caves in Alabama are characterized by incised depictions of animals, humans, composites and/or geometric figures. Each cave environment is different as is each corpus of aboriginal art.

BIOSPELEOLOGY

CAVE AND SURFACE POPULATIONS OF BANDED SCULPIN (*COTTUS CAROLINAE*) IN PERRY COUNTY, MISSOURI: MORPHOLOGICAL VARIATION, ASPECTS OF LIFE HISTORY, AND CONSERVATION STATUS

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Banded sculpin (*Cottus carolinae*) occur in both surface streams and springs in the eastern United States. Occasionally, *C. carolinae* have been reported in twilight or dark regions of cave systems but these populations do not appear to be more than accidentals or troglophiles, exhibiting no cave adaptations. However, several populations of *C. carolinae* in caves in Perry County, Missouri, display characteristics similar to other cave-adapted fish species. Significant morphological differences were found among all populations using discriminant function analysis ($P = 0.0565$). Canonical analysis provided separation based on alterations in eye size, head shape, and the caudal peduncle region. *Cottus carolinae* collected from the caves and resurgence streams in Perry County also exhibit reduced pigmentation and pelvic fin ray counts when compared to surface streams in southeast Missouri and to litera-

ture on other surface populations. The presence of three distinct habitats (cave streams, cave resurgence streams, and surface streams without cave systems) and their corresponding sculpin populations provides an excellent opportunity to investigate changes in morphology and life history in relation to cave adaptation.

TEMPERATURE DATA LOGGING IN MISSOURI GRAY BAT CAVES

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We used digital data loggers to record temperatures in three Missouri caves inhabited in the summer by the endangered gray bat, *Myotis grisescens*. We monitored Bat Cave, Laclede County; Fisher Cave, Franklin County; and Lewis and Clark Cave, Boone County, and outdoor temperatures from 1997 until 1999. The resulting data illustrate phenomena such as subtle changes in ambient temperatures, bat-influenced warming, diurnal bat activity patterns, and short and long-term events caused by weather. In contrast, a study of hibernacula used by Indiana bats (*M. sodalis*) and gray bats revealed dramatic responses to cold fronts at Bat Cave, Shannon County, and other sites. Only 3% percent of Missouri's 5700 caves have significant use by gray and Indiana bats, partly because of their temperature specificity.

USING STYGOBITES TO FOLLOW GROUNDWATER IN TEXAS AND MEXICO

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The limestone that makes up the Edwards Plateau of central Texas and northern Mexico is known for complex and little understood subsurface drainage and consequentially complicated water management issues. To understand patterns of aquifer connectedness, standard hydrologic techniques are used, but techniques such as well drilling are very expensive, and dye tracing across large areas is difficult. This study proposes to use intraspecific molecular phylogenies of populations of stygobite taxa as a measure of hydrologic interconnectedness in order to augment data from standard hydrologic techniques. The first stages of this project will be presented, including: a description of the hydrogeologic setting; identification of appropriate taxa and localities (including the cave-dwelling Cirolanid isopod, *Cirolanides texensis*); and some population size data on Mexican blind catfish, *Prietella phreatophila*, using mark-recapture techniques.

WATER QUALITY IN TWO KARST BASINS OF BOONE COUNTY, MISSOURI

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Urbanization and agricultural land-use activities represent potential threats to the water quality and ecosystem integrity of Devils Icebox and Hunters Caves in Boone County, Missouri. Land use within the Devils Icebox watershed is primarily agricultural and urban, while Hunters Cave is predominantly agricultural and forested. Because these cave systems have very similar geologic and hydrologic settings, the impact of different land-use practices on water quality can be compared. Year-round monitoring was initiated in April 1999, with the objective of characterizing the current water quality status of the main cave streams relative to nutrient, herbicide, and coliform bacterial contamination. In addition, basic water quality parameters (dissolved O_2, pH, temperature, specific conductance, and turbidity) are being monitored at 15 minute intervals. Water sampling for contaminants entails grab samples under baseflow at regular intervals, and runoff event sampling using automated sampling equipment. Chemical analyses include total and inorganic nitrogen and phosphorus and many of the common soil-applied corn and soybean herbicides such as atrazine, cyanazine, metolachlor, alachlor, acetochlor, and triazine metabolites. Bacterial coliform analyses include quantitation of total and fecal coliforms on a quarterly basis.

SOUTHERN INDIANA: A "HOT SPOT" OF SUBTERRANEAN BIODIVERSITY

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The results of several intensive bioinventories from 1993 to present in southern Indiana caves have revealed the presence of three cave systems with 20 or more obligate subterranean species: (1) Binkley Cave System, Harrison County; (2) Wyandotte Cave System, Crawford County; and (3) Lost River System, Orange County. These cave systems are within the Mitchell Plain/Crawford Upland karst of south-central Indiana. The same geologic setting exists, and hundreds of caves are present, in Dubois, Lawrence, Martin, Monroe, and Owen counties, but little is known of their subterranean fauna. However, in 1960 T.C. Barr acknowledged Lawrence County to be a focal point of biodiversity among the troglobitic carabid beetles of the genus *Pseudanophthalmus*, which suggests that more Indiana "hot spots" are waiting to be discovered. To the south, again little is known of the cave fauna between the Ohio River and the central Kentucky karst. In Harrison County, Indiana there are seven species of the milliped genus *Pseudotremia*, but only one species is known to occur in the area between the Ohio River and Mammoth Cave! It is speculated herein that if bioinventories of the magnitude of what has been done in the central Kentucky karst and the Blue River basin of southern Indiana were done in these adjacent areas, a "mega-hotspot" might be demonstrated, encompassing the entire area from Mammoth Cave to Bloomington, Indiana.

A CONSERVATION FOCUSED BIOINVENTORY OF THE SUBTERRANEAN INVERTEBRATES OF THE SINKHOLE PLAIN KARST OF WESTERN ILLINOIS

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In 1998, attention was drawn to the western Illinois karst by the listing of *Gammarus acherondytes* as an endangered species. We suspected that much remained to be learned about the subterranean biota of the area, and in 1998 The Nature Conservancy initiated a bioinventory of subterranean invertebrates in Monroe and St. Clair counties. Sixty-three sites were visited: 39 caves, 14 springs, 5 wells, 4 karst windows and 1 drain tile. A key feature reported for conservation use was an assigned rank of state and global rarity for subterranean taxa. Criteria for these ranks include the number of occurrences, definition of element occurrence, range, and fecundity. Forty-one species of global rarity were reported: 12 - G1, 14 - G2, and 15 - G3. All sites visited were rank-ordered as a function of globally rare species to provide priorities for conservation efforts. Twenty-four taxa of obligate subterranean species were found. The 1978 zoogeographic and evolutionary scenario of Peck & Lewis remained unchanged, but the isolation of the Columbia, Waterloo and Renault karst subunits was illustrated by the endemism of *Mundocthonius cavernicolus* (Renault), and undescribed species of *Antriadesmus* and *Eumesocampa*. Although found outside of the area, within it *Fontigens antroectes* is known only from the Columbia karst, *Ergodesmus remingtoni* and *Arrhopalites lewisi* from the Waterloo karst, and *Stygobromus subtilis* and *Oncopodura iowae* from the Renault karst. *Gammarus acherondytes* was previously recorded from six caves, to which we added six new sites. The amphipod was found in habitats ranging from cave rivers to tiny headwater streams.

MICROBIAL METABOLIC ACTIVITY STUDIES IN PUNK ROCK AND CORROSION RESIDUES IN LECHUGUILLA AND SPIDER CAVES, CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

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Lechuguilla Cave in Carlsbad Caverns National Park contains an extensive microbial community that may cause the dissolution of limestone wall rock, producing a deposit known as "corrosion residue'" (CR). Direct estimates of total and respiring cells in both CR and "punk rock" were made to pinpoint the location of actively respiring cells. Total cells were determined by counting cells stained with acridine orange, a dye that intercalates into DNA, causing cells to fluoresce a bright green under epifluorescent microscopy.

Respiring cells were detected by staining cells on-site with a respiratory dye, ([2-(p-iodophenyl)-3-(p-nitrophenyl)-5-phenyltetrazolium chloride)]: INT). This chemical is taken up and reduced by actively respiring cells, and is seen as a distinct red crystal within the cell using bright-field microscopy. Killed controls and previously live samples were stained with a 0.1% acridine orange solution in the laboratory. Respiring cell counts for CR examined in site one (EA survey) indicate 1.6 x 10^7 cells per cm^3 of material representing 30% of total cells. Cell densities in punk rock were more varied. Respiring cell counts for punk rock examined from site one ranged from 1 x 10^6 to 8.6 x 10^6 cells per cm^3 of material representing 15-29% of total cells. The highest counts were found in site two (Sanctuary) with 2 x 10^7 actively respiring cells per cm^3 of material. The presence of actively respiring cells in the punk rock supports the hypothesis that microorganisms are interacting with limestone walls.

EYES WIDE OPEN: THE "EYELESS" CAVE FISH OF TRINIDAD IS NOT BLIND

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Since being described in 1926, *Caecorhamdia urichi* (Pimelodidae) consistently has been listed as a blind cave representative of the ichthyofauna of Trinidad, West Indies. Our field and laboratory studies strongly suggest that members of this fish population not only have eyes, but also tapetum lucidum and display strong photophobic responses. Morphological variations in eye development and pigmentation could be the result of either an incipient process of troglomorphy (hypogean adaptation) or introgressive hybridization. We believe that this cave "species" is not a valid species at all but rather a deme of *Rhamdia quelen*. We also propose that the presence of tapetum lucidum in this fish is the result of convergent evolution.

COMMUNICATIONS & ELECTRONICS SESSION

A DIGITAL CAVE RADIO USING PSK31

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Digital communication in caves using the amateur radio PSK31 mode can be used to achieve greater range than voice radios without having to learn Morse code. It's easy to build PSK31 cave radio transmitters that are efficient using switching techniques, and the circuitry required for both transmitting and receiving is minimal since the more complex signal processing is performed in a small laptop computer.

THE USE OF RADIOLOCATION AND GPS TO ENHANCE MAPPING ACCURACY AT WAKULLA SPRINGS

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During the winter of 1998/99, Low Frequency Radiolocation gear was used extensively during the Wakulla II expedition to create a 3D Wall map of Wakulla Springs, a Florida State Park. Earlier work had resulted in a mostly line map of much of the Spring. Divers deployed submersible Beacons at intervals through the passages, leaving a marker at each site for later use by the Wall Mapping Team. My job was to locate the point on the surface precisely above each Beacon and provide UTM grid coordinates to the Computer Team.

Great care was used in calibrating the Radiolocation equipment; by divers in leveling the Beacon loops; and by myself in locating each point, resulting in an estimated total "Ground Zero" location error of <1 m.

For planning purposes, a handheld GPS with Coast Guard differential corrections and averaging gave the UTM coordinates with 4 meters expected accuracy.

Midway thru the expedition Trimble Navigation Ltd loaned us a phase differential GPS system with 1 cm accuracy. Conventional surveying with a Leica Total Station was used where multipath would not allow a fix with the Trimble gear. Eventually, every surface point was located to centimeter accuracy.

The average error of the simple Coast Guard DGPS setup for 38 surface points was actually 3.8 meters.

CONSERVATION, MANAGEMENT, AND CAVE RESTORATION

INTERSTATE 66: PROPOSED ALTERNATIVES IN SOUTHERN KENTUCKY AND KARST IMPACTS

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In May of 1999, the Kentucky Transportation Cabinet (KTC) unveiled possible routes for the section of I-66 between London and Somerset, KY. Of the alternatives presented, the most environmentally damaging route was chosen as the preferred alternative. KICK 66 formed as an umbrella organization dedicated to preserving quality of life and environment in the region affected by these proposed corridors. Since the formation of KICK 66, the KTC has retracted their preferred alternative and are reassessing ten alternate corridors. They are also considering modifications to existing Hwy 80.

The proposed route between London and Somerset contains the rugged lands of the Cumberland Escarpment in the Daniel Boone National Forest. The National Forest contains undeveloped woodlands and gorges along Rockcastle River and Buck Creek. The region is highly karstified with a healthy biodiversity. Alternative corridors chosen by the KTC are deficient for reasons including but not limited to:

- Corridors dissect undeveloped land both inside and outside of the National Forest.
- Alternatives cross the Rockcastle River, listed as a Kentucky Wild and Scenic River.
- Alternatives fail to use existing road grades.
- Flanking lands are sensitive to environmental change and contain many protected and threatened species.
- Corridors cross karst topography endangering the integrity of the highway.
- Alternatives do not alleviate traffic volumes into the Lake Cumberland region.

KICK 66 opposes any alternative that would create a new highway corridor through the region. Our position is supported by scientific evidence and backed by local opinion.

KENTUCKY SPELEOLOGICAL SURVEY: FROM CONCEPT TO FOUNDATION

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Development has greatly impacted karst areas and karst biota in Kentucky. Establishing a speleological survey is an important step toward proper planning and zoning in karst regions, implementation of best management practices for karst, and advancing knowledge about karst through well-informed research.

Computer technology will allow the Kentucky Speleological Survey to be developed and managed efficiently. Appropriate accessibility will be an essential component. Government, community, and conservation needs must all be considered. Therefore, provisions will be made for release of certain types of data to the public and government agencies to help prevent karst damage and human casualties. Public education must be a priority. Data contained in a speleological survey must be accessible to help educate landowners and to forward the benefits of karst science. At the same time, sensitive data must be reserved from the public.

To date, four Kentucky Speleological Survey organizational meetings have been held in Lexington. Individuals representing several regional organizations have attended and expressed their views. Resolutions have been reached. A ratifiable draft of the Articles of Incorporation has been produced with a complete draft of the bylaws under review.

CONSEQUENCES OF PUBLICITY: ARE THERE UNINTENDED CONSEQUENCES OF MASS CAVING PUBLICITY FOR CAVE CONSERVATION AND MANAGEMENT?

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Publicity about caving has benefits as well as unintended consequences. Publicity can influence the public to appreciate caves, support protection, and encourage responsible and safe caving. But there is also some evidence of negative consequences; specifically an increase in "naïve novice" accidents, persistent over-trafficking, and vandalism in technically difficult caves. There may be analogous developments in mountain biking and "outlaw" rock climbing.

We developed a "byproduct" model suggesting that, in addition to the benefits of mass publicity, a small but significant population of unaffiliated cavers is being produced. Our "advertising" raises interest in caving, yet some forget or ignore educational messages.

We propose a mechanism (Interest-Ability-Opportunity-Action) for the model that explains why publicity does not cause most people to go caving, but those who do sometimes bypass the NSS. The reason may be that, in many parts of the US, caves are more accessible than NSS members. There is also a tendency to go caving within existing social circles. We suggest that advertising or publicity, even if educational, may produce a significant stream of cavers who proceed to undo many of the benefits of cave education.

SECRET CAVING: TRENDS, SOCIAL MECHANISMS, AND IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

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Karst with cave entrances is a finite resource. As the caver population grows, there is increasing competition for new or extended caves. The required investment of work increases, as does the risk of failure. Many obstacles may have to be overcome with multiple technologies. In this environment of "sustained-difficulty caving," secrecy has become a way to protect investments. It also serves as a social stimulant for small cadres of cavers who seek length and depth records.

Some cavers object to secrecy on Positivist grounds of information sharing and scientific progress. I suggest that in the Internet age this is simplistic, and that commercial proprietary rights are a useful analogy in many situations. Secrecy is often simply the first stage of an exploration, documentation, and publication cycle.

What are the implications for conservation and management (C&M)? Far from being selfish, secret cavers are usually driven by conservation and landowner protection concerns. They often need cave evaluation, management models, case studies and other assistance from the C&M community. I will focus on eastern, privately owned caves but there are also interesting developments in public-lands caving, including formal and informal arrangements between land managers and cavers who wish to invest in exploration projects.

RESTORATION TECHNIQUES FOR SEMI-PRISTINE PASSAGES: PELLUCIDAR IN LECHUGUILLA CAVE

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Low-impact restoration strategies were used to restore Pellucidar, a semi-pristine passage of Lechuguilla Cave. Pearls, pools, and flowstone surfaces tracked with mud and corrosion residue from boots were cleaned. The six-day restoration expedition required tools that were small and lightweight, but sturdy and efficient. Silt was cleaned out of pools with a vacuum pump that filtered and re-circulated water back into the original source. More than 4 m^2 of mud-tracked pearl beds were restored. Some of the effort required hanging on rope to reach work sites. Flowstone was mopped, embedded corrosion residue was scrubbed, and grit was removed.

VOLUNTEER VALUE FORMS

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A system for calculating Volunteer Value (VV) grew from opposition to Cave Fee Demo. Coordination between the US Forest Service and the NSS has produced a VV agreement based on government rates. Generic forms have been created for documenting volunteer time contributed to any project. Forms can be used for recording efforts in survey, science, conservation, photography, etc. Though the VV recording system was created as an adjunct to the agreement between the Forest Service and the NSS, the system can be applied to volunteer efforts in caves managed by other federal agencies, states, conservancies, or private owners. We encourage cavers to begin using this system to document monetary values of work and expertise.

DEVELOPING A CAVE POTENTIAL MAP TO GUIDE SURFACE LAND USE MANAGEMENT DECISIONS AT WIND CAVE NATIONAL PARK

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To promote better surface land use management decisions at Wind Cave National Park, a management concept using a cave potential map was developed. Because of hydrologic connections between surface gullies and the cave, and the continual enlargement of the boundaries of the cave due to on-going exploration, it was logical to base surface management decisions on the potential of Wind Cave being located below any given point in the park. To develop the cave potential map, several data sets were gathered, including: structural geologic factors, a contour map, plan and profile views of the cave survey, radio location data, geology map, blowhole location map, water table contour map, GIS generated TINS, orthophotoquads, and a park boundary map. By combining these data sets, the maximum possible extent of Wind Cave was determined. By calculating passage density for the current cave boundaries and then for the maximum potential boundaries, a minimum and maximum potential survey length was determined for Wind Cave. It was determined that the current cave boundaries cover 1/8 of the total potential or maximum extent of the cave. Interestingly, the maximum potential boundaries are 98% inside of the current boundaries of Wind Cave National Park.

CAVE ENTRANCES IN CAVE RESOURCE PROTECTION: A VIRGINIA PERSPECTIVE

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To many cavers, each cave is unique: no two caves look alike. In fact, no two caves are alike. Each contains a unique array of resources annotating origin and development, past use by organisms, present ecosystem, and a range of conditions and substances and defining patterns of dissolution and deposition.

Some resources are one-of-a-kind: the setting and orientation of each fragment provides forensic evidence of a cave's origin, of animal activities, the manner of death, or burial history. The disturbance of context of archaeological and paleontological materials may destroy far more information than the material goods offer. Cave entrance control may be the key to protecting archaeological, geologic, historic, and paleontological cave resources.

The health or life of a cave, physically and biologically, involves much more than the control of who enters the portal to the underworld. Unaltered land-use over a buffered footprint of a cave is important in preserving conditions of moisture and nutrients in the terrestrial habitat of the cave. The question is how far to extend the buffer beyond the cave footprint. Trogloxenes that forage outside of the cave are dependent on a stable surface ecosystem overlying the cave. An extreme example includes the foraging areas (extending kilometers) used by maternal bat colonies or swarming bats as they gain weight before hibernation. By far the most significant resource buffer encompasses the recharge area (authigenic and allogenic) for caves with vadose or phreatic components and their associated ecosystems.

A SUMMARY OF LEGISLATION AND ORGANIZATIONS INVOLVED IN THE PRESERVATION OF CAVES AND BATS

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The conservation of bats and caves in our national parklands has come a long way since the National Park Service was founded in 1916. Awareness of the importance of bats, not only to park ecosystems, but also to surrounding areas, is much greater today. Speleologists should have a working knowledge of the National Park Service Organic Act of 1916, Federal Cave Resources Protection Act of 1988, the Endangered Species Act of 1973, as amended, the National Environmental Protection Act of 1969, the Lechuguilla Cave Protection Act of 1993 and the National Cave and Karst Research Institute Act of 1998. These Acts specifically protect caves on Federal Lands for perpetual use, enjoyment and benefit of all people. There are 25 states with cave protection laws. The definition of a cave varies widely by state and ranges from a "historic site", as defined in Vermont, to Kentucky's definition of "any naturally occurring void, cavity, recess, or system of interconnecting passages beneath the surface of the earth containing a black zone including natural subterranean water and drainage systems, but not including any mine, tunnel,

aqueduct, or other man-made excavation, which is large enough to permit a person to enter."

MINIMIZING ALGAE GROWTH ALONG TOUR ROUTES VIA LIGHT WAVELENGTH SELECTION

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Photosynthesis is driven primarily by red and blue light. Blue-green (bacterial) algae have pigments (phycobilins) that can absorb yellow light, but non-bacterial algae, mosses, and all higher plants cannot. As well, even blue-green algae do not grow as vigorously on yellow light alone. In the Frozen Niagara section of Mammoth Cave, we have installed gold phosphor fluorescent lights, and ultra-yellow LED lights along one segment of the trail as a test. Algae and other plant growth were removed by the standard bleach treatments following installation, and the test period will extend for two years.

DIGGING SESSION

THE CAVE DIG TOURIST: RATS NEST, HELICTITE, AND BIG BUCKS PIT

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Cave digging and stabilization is a major part of modern cave exploration. Some of the cave digs conducted around the US and the world are amazing feats of technology and perseverance. Three examples provide ideas and inspiration: (1) In Rats Nest Cave (Alberta, Canada), Chas Yonge did solo trips to mine upwards through a breakdown pile. He constructed The Box, a shoring structure, to stabilize the resulting passage. The Box has an innovative cap to keep debris from falling into it. (2) The entrance to Helictite Cave (Virginia) was dug open by Phil Lucas and others despite naysaying by prominent cavers. As the cave became longer, Phil installed a culvert gate with an air seal to prevent drying of speleothems in the cave. The cave is now over 9 km long, and a strategic lead is being excavated with dual plastic toboggans for hauling spoil. (3) Barberry Cave (VA) needed a new entrance to bypass low airspace and landowner problems (Sept. 1999 NSS News). Nevin W. Davis launched an effort that sank a 20 m shaft into the cave, thus creating Big Bucks Pit. The effort required a great deal of engineering and problem solving. The total cost was over 1200 person-hours and $4000.

EXPLORATION - INTERNATIONAL

THE PIT, SISTEMA DOS OJOS, MEXICO

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Originally discovered in 1994 by Dan Lins and Kay Walten during a 1500 m, double-stage, scooter-assisted cave-dive, The Pit is an unusually deep, water-filled cave in the middle of the Yucatan Peninsula, Quintana Roo, Mexico. The initial exploration discovered an adjacent entrance cenote that has allowed easy access to The Pit and facilitated extensive, deep-diving explorations of the cave. In February 2000, a small team established a camp around the entrance of The Pit. Using rebreathers, the dive-team continued exploration of the cave at depths exceeding 101 m. During 20 minute penetration dives, with up to 6 hours of decompression, the team discovered a major north-south trending passage. To the north, the cave continued for 76 m, ending in a solid wall at a depth of 113 m , while to the south the passage continued a significant distance, to a tight, silty, phreatic tube at 119 m. The divers also retrieved samples from the cave which suggest that the cave developed through a dolomitic layer between the extensive limestone bed of the Dos Ojos system, at 12 m and a much deeper layer around 101 m. This lower layer is significant as sea levels during the last glacial epoch were at this depth, indicating favorable conditions for significant horizontal development. In addition, hydrologic data suggest that The Pit may be an entrance to the main drain of the Dos Ojos system, and possibly several other caves of the Yucatan interior.

SUMMARY OF TWO YEARS OF CAVE EXPLORATION IN THE DOMINICAN REPUBLIC

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From November 1998 to summer 2000, over 100 caves in the Dominican Republic have been studied using a multidisciplinary approach. Each cave was assessed for archeological interest, paleontological material and biological content. Nearly 100 caves were surveyed with maps drawn, and another 30 caves that already had adequate maps were visited. Qualified archeologists documented over 1000 pictographs and petroglyphs and examined pottery from several different pre-colonial cultures. Paleontological collections were made in many caves, and radiocarbon dating of both bones and calcite layers produced new earliest occurrence dates (*Brotomys*: 430 ± 50 yr. BP; *Isolobodon*: 710 ± 50 yr. BP as well as the oldest known Quaternary age fossil bones from Hispaniola (*Parocnus*: 112 ± 6 ka). Biological collections of invertebrates from the caves have revealed a diverse fauna, yet no new terrestrial troglobites. Over 80 caves were documented as having at least some use by bats, with the largest known population including nearly 300,000 individuals, and a single cave with at least 8 species of bats.

CAVES OF THE MATANZAS/BELLAMAR KARSTS, NORTH CENTRAL CUBA

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The great limestone plateaus of the Matanzas coastal plains are some of the best known karsts in Cuba, but are still poorly explored. Several new extensions of older classic caves (creating some systems >25 km) and a new inventory that has counted >3000 entrances gives a hint of the potential in this zone. Among the more unusual cave features are extensive areas of folia in systems that show evidence of saline water incursions. These zones of folia may be the most extensive known (as much as 1.5 km of nearly continuous display). Other forms include dolomitized speleothems and diverse calcite crystal forms. The Jarito/Bellamar System is a spectacular example of a highly mineralized cave with ongoing exploration. The small group of local cavers is actively expanding the limits of these complex, mostly horizontal caves. Current travel times to the outer limits are now over 8 hours. Diving potential is also spectacular here with massive clear water tunnels that could extend well into the offshore resurgences. The pristine nature of the caves is remarkable despite the proximity to large populations. The exceptional delicacy of the crystal structures is clearly world class.

VIETNAM RECONNAISSANCE 2000

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In April 2000, an American group of cavers began to establish a working relationship between the NSS and the Hanoi University of Science. Of the several areas we visited, we chose northern Lao Cai Province as the primary focus for a future expedition.

CAVE RECONNAISSANCE IN THE SAN GABRIEL AREA, SAN LUIS POTOSI, MEXICO

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The San Gabriel area, about two hours by dirt road south of Ciudad Maiz, was checked during a March 1998 trip. Local people welcomed us and indicated that we were the first Anglos to visit the area. Numerous large sinks and several ridge-flank insurgences were checked. Cueva de San Gabriel was pushed through tight canyons and 8 drops to a small sump at –85 m. Cueva de los Ecos was pushed down 7 short drops, before ending in a deep sump at –95 m. Sótano de Tepozan was a deep pit ending in a chamber at –90 m. Thirteen other caves were mapped, and about a dozen entrances were GPSed but not entered due to time constraints. The area is extensively karstified, but is presently arid. It does not appear that any large caves are present or at least accessible.

THE CAVES OF CAYMAN BRAC

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Located about 242 km south of Cuba, the island of Cayman Brac is host to hundreds of small caves. The island is about 19.3 km long, about one-and-a-half kilometers wide, and is composed of marine limestone. Extending the length of the island is a bluff that starts at sea level at the west end, and rises smoothly to sheer 43 m cliffs at the east end. The island's limestone karst, locally known as "Ironshore", is very hard, spiky, and sharp, which makes inland travel and vertical ropework very difficult. The climate is semi-tropical with high temperatures and humidity, both above and below ground. The

island's caves can be categorized into four main types: mini-cockpits, cliff face caves, joint fractures, and classic sinkholes. Many of the cockpits are located along the top of the bluff along the eastern end of the island. Most of these pits are about 9 m deep with a diameter of ~6 m. In some areas there are 30-40 separate pits in a single acre of land. The cliff face caves number in the hundreds and the entrances reside anywhere from sea level up to the top of the bluff. The joint fracture caves are a series of parallel joints trending at ~60º. These caves quickly intersect the water table and continue along the joint as heavily decorated phreatic passages. The western end of the island contains a variety of small sinkholes.

RECENT EXPLORATION AND DISCOVERIES IN CUEVA DE LA PUENTE, SAN LUIS POTOSI, MEXICO

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Cueva de la Puente, a popular sport cave near San Luis Potosi, is visited each year by hundreds of people. Intending to update the 1972 map, we began a resurvey in 1998. On the first trip, we found a bypass to the upstream sump and our simple resurvey was transformed into a serious project. Since then, we have added kilometers of passage upstream and near the tourist route, connected new entrances, and discovered the world's longest soda straw (9.63 m). After every trip, our reports were met with incredulity from the Mexican and American cavers who had assumed they knew the cave well. Magnetics in overlying volcanic deposits and industrial material in parts of the cave have made some survey difficult, but work in La Puente is generally very pleasant. The large passage, historically called "the main cave", is only an infeeder; recently discovered upper level passage gives new meaning to the term borehole. While most of the obvious leads are finished, work remains. The cave will likely extend to a large sink 8 km away.

NEW ROADS TO TAMAPATZ: A CAVING AREA REVISITED

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Mike Walsh, editor of the 1971 SWT Guide to Mexican Caving, instigated a project to gather information for a revised edition, starting with Tamapatz. This is arguably the most popular Mexican destination for American cavers who make pilgrimages to the big pits: Sótano de las Golondrinas, Hoya de Guaguas, and Sótano de Cepillo. The area has dozens of other caves: huge fossil borehole, sporting wet multi-drops, and, of course, more pits. New roads begun in the mid-90s now provide easy access to the area. Many caves that were hours hike 30 years ago are just minutes from parking. Roads go into areas that had been too remote to consider 30 years ago. Nearly 160 km of road have been recorded and more than 20 caves have been located and revisited. In the process, several new caves were accidentally found. Not surprisingly, some of the known caves have yielded passage missed in the 60s and 70s. The Tamapatz area is rich with opportunity. Hopefully, publication of the new road logs will not only make visiting the pits easier, it will encourage cavers to broaden their experience of Mexican caves and reopen the area to exploration.

PROYECTO LAGUNA DE SANCHEZ, NUEVO LEÓN, MÉXICO

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Since 1996, cavers from Texas, Pennsylvania, Utah, and Germany have been finding, exploring, mapping, and inventorying caves near the Ejido of Laguna de Sanchez south of Monterrey. Two caves were previously reported, including El Infierno de la Camotera, a 55 m drop into a large room containing the largest known summer colony of the endangered nectar-feeding Mexican long-nosed bats. More than 50 other caves have been recorded in about 7 trips, and several new karst areas have been discovered. Most of the caves are short dead-bottom pits or simple crevice-type caves, but several have proven to be fairly complex. While not a world-class caving area with long and deep caves, the number, diversity, and access have allowed us to explore lots of virgin passage. Combined with spectacular scenery and friendly locals, the Laguna de Sanchez area has been a fun place to visit.

EXPLORATION IN THE SAO VICENTE SYSTEM, GOIAS, BRAZIL

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Cavers from Brazil, Slovenia, and the United States gathered in a remote part of central Brazil to extend the length of one of the country's largest caves. Ten kilometers were surveyed in the Sao Vicente System with 6 km consisting of new survey and significant finds including a large new discovery (the Talameira Room) and a new entrance that allows access to a remote part of the cave. Leads off the Talameira room have the potential to connect to a large neighboring cave, the Angelica-Bezerra System. Surface exploration of the nearby pinnacle-ridden karst plateau yielded 14 smaller, new caves within a period of 3 days and within an area no larger than a football field. Great exploration potential remains in this infrequently visited area.

GUNUNG BUDA PROJECT 2000

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Gunung Buda is a limestone mountain located in a spectacular jungle area just north of Mulu National Park in the Sarawak region of Malaysia on the island of Borneo. In February and March 2000, a 6-week-long expedition returned to Gunung Buda ("White Mountain") and mapped >25 km of cave passage. Over 4.5 kilometers were surveyed in newly discovered Spirits River, an unusual stream cave developed in an extremely thin bed of limestone and characterized by mazy passage intersected by many beautiful skylights. Another significant discovery was Buda River Cave, with 2.5 kilometers of passage including a fun "through-trip" down the Buda River, which is sure to be a major attraction in the proposed national park. A resurvey of Compendium Cave, originally mapped by the British, produced several kilometers of virgin passage and appeared to be a key to the northern part of the Gunung Buda area. In addition, Babylon Cave and Disappointment Cave were connected. Significant discoveries were made in several other caves with over 90 km of cave found in this impressive tropical karst area.

EXPLORATION AND CAVE DIVING IN THE CHIQUIBUL SYSTEM OF BELIZE AND GUATEMALA, CENTRAL AMERICA, 1998-99

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The 1998 expedition was funded by the National Geographic Society [NGS], with permits from Government of Belize agencies. The primary goals were sampling for speleothem- and paleomagnetic-dating analysis in the several levels of the system, and to expand collection areas through discovery of new passages. One project focus was to descend the Zygote Chamber pit and explore the Chiquibul River; aids to exploration were LED lamps developed by Jim Locascio and Peter Shifflett. Steve Alvarez joined Jean Krejca, Tom Miller, and Shifflett in surveying the river upstream to Eel Sump. Miller and Krejca also explored downstream from Zygote, discovering huge borehole; later with Shifflett they reached a sump presumed to be the other side of Actun Tunkul's terminal downstream sump, reached in 1984. Exiting after eight days underground at Camp I, most of the 8-person team were reluctant to reenter. 1999 was supported anew with NGS funding and British Army airlifts (including scuba tanks). Cave-divers James Brown, Miller, Shifflett and Krejca entered Tunkul with one support crew, while another team entered Cebada Cave. Following Brown's 60 m connection dive, all four divers swam into Cebada, eventually locating their missing support team. From Camp II, Eel and Shrimp Sumps were dived to a fourth sump where exploration ended. There was little enthusiasm for the lengthy second underground camp, but survey this time extended Cebada-Tunkul to almost 40 km. A notable extension was made through Stan Allison's dig in Nighthouse Cave, bringing the Chiquibul System total to 65 km.

CUEVA CHARCO: EXPLORATION OF MEXICO'S LATEST KILOMETER-DEEP CAVE

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A multinational team of cavers spent several weeks during March 2000 pushing Cueva Charco to a depth of -1019 meters. The cave, situated in the Mexican state of Oaxaca, was discovered in 1989 and exhibited potential as a pathway into the theorized downstream portion of Sistema Cheve. Following one week of rigging, support and supply trips, a rudimentary underground camp was established at an ~600 m deep. The first few survey trips out of this camp soon revealed that the cave was paralleling the projected trend of Cheve. Charco was not going to make the connection but was instead dropping rapidly and becoming a respectable cave of its own. Kilometers of beautiful sinuous stream canyon and waterfalls were surveyed below camp by 13 team members. The cave's difficult nature required significant physical strength and stamina and it exacted its toll on the explorers. More than a week was spent exploring from the underground camp and exploration was suspended when the rope supply was exhausted. A narrow stream canyon continues beyond the last survey station, and there is no indication that the cave is going to end anytime soon.

EL PAISAJE ESPELEOLÓGICO DE CUBA (THE SPELEO SCENE IN CUBA)

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Cuba no es simplemente una Isla, geográficamente constituimos un archipiélago de cientos de islas y miles de cayos que tienen como base la plataforma submarina del territorio. El área insular es de 111 111 km^2 y posee miles de grutas, cuevas y cavernas verticales. Debido a la magnitud y riqueza de nuestro subsuelo cársico los cubanos la llamamos el "Archipiélago de las cavernas". Las zonas espeleológicas de nuestro territorio están distribuidas en las llanuras cársicas de la Habana - Matanzas, Villa Clara - Cienfuegos y las del norte de Sancti Spíritus. Las regiones montañosas de la Sierra de los Organos en Pinar del Río tienen gran importancia no solo por sus bellezas naturales sino por su geología y lo mas importante en ese aspecto son las amonites del Jurásico que se han encontrado en ésta región. Otra zona espeleológica montañosa son las alturas de Guamuhaya en la zona central de la isla, con sus famosas cúpulas, conos de grandes cañones y cuevas fluviales verticales. La región oriental posee las montañas mas altas del territorio y las menos estudiadas, también con grandes cúpulas, ríos importantes e impresionantes cañones. Estas alturas ocupan las provincias de Granma, Guantánamo y Santiago de Cuba.

Cuba is not simply an island. Geographically, it is made up of an archipelago of hundreds of islands and thousands of cays that have the same territorial submarine platform. The interior area is 111,111 km^2 having thousands of grottoes, caves, and vertical caverns. Owing to the magnitude and riches of our karst subterranean earth, the Cubans call it the "Archipelago of the Caverns." The speleological zones of our territory are distributed in the karst plains of Habana - Matanzas, Villa Clara - Cienfuegos and the north in Sancti Spiritus. The mountain regions of the Sierra de los Organos in the Pinar del Rio have great importance not only for their natural beauty but also for their geology and, most importantly, because Jurassic ammonites have been found in this region. Another mountainous speleological zone is the heights of Guamuhaya in the central zone of the island, with its famous domes, grand canyons and vertical river caves. The eastern region has the least studied and tallest mountains of the territory, as well as the grand domes, important rivers, and impressive canyons. These highlands occupy the provinces of Gramma, Guantanamo, and Santiago de Cuba.

English translation provided by Andrea Futrell

EXPLORATION – U.S.

WAKULLA 2 EXPEDITION—EXPLORATION AND LOGISTICS

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During the 3 month Wakulla 2 Expedition, a total of 894 m of new discoveries were made in Wakulla Spring, FL. Exploration was difficult in this cave, which lies at 100 m water depth. The lead dive teams used MK5 rebreathers with ranges of 8-12 hours, independent of depth. Custom-built diver propulsion vehicles had a battery range of about 20 km. Decompression was accomplished in a commercial chamber placed on a floating barge in the spring pool. At the end of their diving missions, divers entered a personnel transfer capsule at 24 m or 33 m, were raised under pressure, and docked with the main chamber. Decompression generally took 10-13 hours in the chamber after a much shorter period of in-water decompression necessary to arrive at the transfer capsule.

The project involved 151 volunteers from 8 countries. Of these, 11 lead divers were rebreather-trained, fully cave certified, and experienced enough for multi-hour missions at -100 m. The rest of the team included support divers and additional crew that assembled diving gear before missions, properly attended gear after missions, downloaded computer data, assisted lead divers, tended lines during raising and lowering of the transfer capsule, located surface radio beacon points, etc. The primary goal of the expedition was to create the first fully 3D cave map. However, the techniques used for this expedition can be a model for exploring other long and/or deep underwater caves.

FAIRY CAVE, COLORADO

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Although originally opened as a commercial cave in 1896, established cavers did not begin exploring Fairy Cave until the early 1950s. In 1960, significant air was discovered emanating from a small rift called "The Jam Crack". Enlarging the "Jam Crack", cavers gained access to a larger, lower level, including "The Barn" and highly decorated "King's Row". Discovery of this lower level rekindled the idea of commercializing Fairy Cave and the cave-property changed hands in 1961, to remain closed to all but limited exploration for the remainder of the century. Still believed to be the most decorated cave in Colorado, caver-developers finally leased the property in 1998 and began commercializing Fairy Cave. This new development also facilitated access of cavers, surveyors, and digging teams into the cave. Since then, the length of the known cave has rapidly expanded from 1200 to nearly 4600 m. Recent discoveries include: the pristine Beginners Luck, characterized by significant flowstone and the caves only lakes; Discovery Glenn, a large room with significant iron-foam deposits; The Paragon Disco, a complex maze of tight, corroded passages; and the spectacular Gypsum Halls, which as the name suggests, contains significant gypsum deposits. As more of the cave is surveyed, joint control patterns indicate a possible origin for the cave from the nearby sulfur-springs. In addition, significant airflow continues to emanate from several places in the cave, suggesting that much more remains to be discovered.

CAVES OF THE 1843 FLOW, MAUNA LOA, HAWAII

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The 1843 flow lies below the NE rift zone of Mauna Loa, on the Big Island of Hawaii. The flow ranges in elevation from 3500 m down to 2000 m, covering an area of 51.7 km^2. Aerial photographs show numerous large pukas and trenches in this shelly pahoehoe flow, including one puka over 60 m wide. Since 1992, HSS members have found and surveyed a total of 16 caves in the main portion of the flow, between 2900 m and 2300 m. Dave Bunnell, Don Coons, and Doug Medville made the most significant find was this year, surveying 729 m in Booty and the Beast, a voluminous tube with large breakdown mountains. Like many of the 1843 caves, it contained unusual mineralization, including gypsum rims. A similar tube system may await us in the middle of the study area, over 3 kilometers from the nearest road.

THE EXPLORATION AND SURVEY OF EMESINE CAVE, HAWAII

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Emesine Cave is below the northeast rift zone on the island of Hawaii. This large and complex lava tube is found in the historic 1880-81 flow which extends for 45 km from an elevation of nearly 3500 m to almost sea level. With a surveyed length of nearly 14 km and a vertical extent of over 400 m, Emesine is one of the world's most significant lava tubes. Segments of cave have been explored and surveyed in several areas along the flow, including the well known Kaumana Cave on the outskirsts of Hilo.

THE EXPLORATION OF THE KULA KAI CAVES, HAWAII

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The Kula Kai caves are located at Ocean View, in the southwestern part of the island of Hawaii. In this area, four large lava tubes containing over 13 km of surveyed passage have been mapped during the past two years. On the most recent expedition, two of these were connected, giving a single tube over 8 km of length. The tubes exhibit a distributary pattern with as many as 7 large parallel passages coursing together down the mountain's flank

NEW DISCOVERIES IN TRIPLE ENGLE PIT, GYPKAP, NEW MEXICO

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Triple Engle has remained one of the longer (1.6+ km) and the deepest (136 m) of the GypKap caves for several years. It is the deepest known gypsum cave in the US, and one of the deepest in the world. In October 1999, Rich Knapp led a trip to push a significant lead at the perimeter of the BF Room. After negotiating the low airspace of Jabbas, we descended into the BF Room and began surveying in walking passage. A long day ensued, with many stations and flashbulbs shot in virgin passage. This trip led to about 300 m of new passage in a significant extension.

PROGRESS IN LECHUGUILLA CAVE: 100 MILES AND BEYOND

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The length of Lechuguilla Cave (Carlsbad Caverns National Park, New Mexico) continues to grow, with over 8 km added in 1999. The cave has been closed over the past winter and spring while the culvert and gate were replaced. During expeditions over past two years, LEARN (Lechuguilla Exploration and Research Network) and other cavers made new discoveries that drove expeditions deep into the western and eastern branches. In addition, a 7 pitch climb in the southwest branch led to Delilahs Spiral Staircase and the highly decorated Jewel Box. Frost Works, festooned with aragonite and calcite crystallization, was found south of the Western Borehole in 1998. In 1999, La Vida de Altibajos was found below the Far Planetarium. Last August, a push team surveyed through an airy crack under layers of breakdown north of Keel Haul, opening Northern Exposure, a new route heading northwest off the map. Large chambers with impressive aragonite "trees" adorned this new finger, which pushed the westernmost extent of the cave beyond the Rainbow Room. Meanwhile, the Far East yielded new passages for hearty cavers. Climbs near Grand Guadalupe Junction led to a series of ascending chambers such as El Nido del Lobo and Century Hall in late 1998, breaking 100 miles. Last year the Kachina Lakes were found and numerous leads were pushed near La Morada Maze. With methodical pre-expedition homework, and cavers willing to push crawls, cracks, climbs, and boneyard, exploration will continue to be rewarded in this grand cave.

EXPLORATION OF THE BIG RED TUBE, MAUNA LOA, HAWAII

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With a surveyed length of nearly 3300 m and a vertical extent of 231 m, Big Red is a vertically extensive lava tube in a prehistoric flow below the northeast rift zone on Mauna Loa. The tube's entrances were seen from the air in 1996 but not visited until the spring of 1999. The Big Red tube is notable. Its passages are 17-18 m below the surface; deep for a lava tube. Also, its lower end is 1800 m from the nearest entrance, fairly far in for a lava tube, and is over 490 m beyond the end of the surface exposure of the flow containing it. Finally, the tube contains the skeletons and remains of over 100 bats, some of which may be extinct. This appears to be the largest number of bat remains so far found in a Hawaiian lava tube.

PRELIMINARY REPORT ON HUALALAI RANCH CAVE, HAWAI'I

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The Hualalai Ranch Cave is a very large braided lava tube system that originates near Puu Alauawa at ~790 m msl on Hualalai Ranch, and lies in a 4.7 ka flow unit that stretches downflow to the coast near Kaupulehu. Over 16 km of mostly interconnected passages have been surveyed during the five survey expeditions conducted over the past three years. Survey work is continuing.

The cave contains significant features. Native Hawaiians apparently used the caves for water collection, rituals, shelter, and burials. The systematic exploration and survey have, so far, produced the discovery of three human burials, as well as a considerable evidence of other occupation and use by the early Hawaiians. Much new material was located during the field surveys, compared with an archeological survey previously performed on the site.

Notable other features of the cave include geology, animal fossils, unique mineralogy, and habitat for endemic species of animals and plants. The cave is significant for its length and braided complexity and also contains unique secondary mineral deposits such as gypsum beards and crusts, which are among the best examples known from lava tubes. Additionally, bird skeletons have been located, some of which have been identified as extinct species. The cave entrances, i.e. pukas, appear to be a preferred habitat for several species of endemic native trees and plants, including the *halapepe* and *ohe makai* trees. Native insects, apparently living on tree roots that hang into the cave passages, have also been found in the cave.

MARBLE MOUNTAIN, COLORADO: HOME OF THE EXTREME AND SUBLIME

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In the last 10 years, there has been renewed interest in exploring the caves of Marble Mountain in the Sangre de Cristo Range in Colorado. These include: Spanish, White Marble Halls, Franks Pit (the upper entrance of Spanish), Davis Sink, Burns, Ladder, Moonmilk, and Elderberry. Exploration has been slowed by the challenging conditions in getting to the caves and being able to endure the cold underground environment. At an altitude of 3580 m, the caves are inaccessible all but a few months of the year.

Our work has involved trying to tie the caves together. Intuitively, one senses that they were all connected at one time. Indeed, we have confirmed by smoke tracing that Davis sink connects to White Marble Halls and the Sucking Tube connects to Franks Pit. Our surveys have shown the close proximity of Spanish with Burns and Moonmilk. Most of the survey work done in the past is incomplete and doesn't represent the more recent discoveries. We have used a GPS receiver to accurately locate the entrances. As surveying continues, we are beginning to see the relationships of the systems. Spanish Cave has much folklore surrounding it. The stories of hidden Spanish gold, mining, Indian slaves, human bones, the Maltese cross, and an old fort have attracted many a non-caving person. Spanish is such an uninviting cave that most non-cavers never go in more than ~10 m.

EXPLORATION - VIRGINIA CAVE EXPLORATION SYMPOSIUM

RAINYDAY WOMAN AND THE ALLEGHANY BLOWHOLE

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Alleghany County showed 64 caves in Douglas' *Caves of Virginia* (1964). Holsinger's *Descriptions of Virginia caves* (1975) showed 75 caves. By 1996, Alleghany had over 150 known caves and was just about to open up.

For two years we focused on a series of caves along a mountain west of Horton. The entrances are located 10–60 m above a stream, all within ~1.2 km. We decided to survey the smaller caves before tackling the main cave.

We completed five maps before we started Alleghany Blowhole. The first trip produced 200 m of survey. The second doubled the extent of the cave by opening a virgin breakdown area to a tiny window over a 7.6 m drop and two more levels of passage. Over time these passages led to complex breakdown that produces more leads every trip.

Meanwhile, across a shallow ravine, a tiny hole blew lots of air. This dig yielded Rainyday Woman where pits lead to a lower level (filled with huge breakdown) with a ceiling, but no walls or floor. This has been connected from the breakdown in Blowhole. In another direction, the cave passes under a surface sink and heads directly for the main cave.

We have yet to begin the 'main cave' on the property, although we may get there from inside. There are two more known caves and simple wandering around has produced at least two leads. We look at the upper reaches of the mountainside and wonder what serious ridgewalking will find.

THE EXPLORATION OF DOE MOUNTAIN CAVE

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Doe Mountain Cave is located in Giles County, Virginia. It is owned by the Knipling family and is on their 1400 hectares property that serves as a family retreat and hunting club. In 1996, they found a blowing crack along the side of a ravine coming off Doe Mountain. Intrigued, they set about enlarging the entrance with a grinder and, in the spring of 1998, were able to get in. Two trips were taken and approximately 450 m of tight, wet vertical cave was explored.

In the summer of 1998, I moved into a house across the road from the Knipling property. I met the Kniplings during Halloween, when they were down for a weekend of hunting. They showed me the entrance and were very enthusiastic when I volunteered to survey the cave. The first survey trip was in the middle of December and netted 490 m with an additional 150 m explored to the top of a 3 second pit. In January of 1999, the entrance was enlarged to accommodate everyone and surveying began on a regular basis. Subsequent trips have revealed a very complex, wet vertical cave with almost 5 kilometers of surveyed passage and a depth of over 180 m. The cave has five pits in excess of 30 m. One, Mega Dome (at 68 m, the third deepest pitch in the state) was climbed from the bottom. Approximately 50 leads still remain unchecked and the cave still holds much promise for additional length and depth. Doe Mountain Cave is developed in the upper Middle-Ordovician limestone along the flank of a plunging anticline.

EXPLORING CORKSCREW CAVE: TAZEWELL COUNTY, VIRGINIA

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The story of Corkscrew Cave began in 1999 with the discovery of a blowing entrance on the flank of a ridge in Tazewell County, Virginia. Exploration and survey of the seemingly unremarkable cave quickly led to the serendipitous discovery of Virginia's deepest vertical shaft (103 m). Subsequent aid-climbs in this breathtaking pit and beyond, were instrumental in the breakthrough into an extensive multi-level, multi-kilometer labyrinth of active stream trunk and paleo borehole. Exploration of Corkscrew Cave continues at a steady pace, resulting in exciting discoveries with every trip. All indications are that many more kilometers of passage will be found and that this is only the first chapter of a multi-volume tale of exploration and discovery.

THE EXPLORATION AND DIVING OF THE AQUA CAVE SUMPS

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Aqua Spring is a major resurgence draining Burnsville Cove and its 80+ km of surveyed cave passage (which include Butler and Breathing caves and the Chestnut Ridge Cave System). In 1956, before many of these caves had been entered, Bevin Hewitt dove the submerged entrance to the spring. Within 5 m, he popped up into hundreds of meters of large, clean, beautiful stream passage. A "dry" entrance was later opened just off to the side of the spring. At the back of the cave, passage ended at a deep sump pool known as French Lake. Although the years saw the survey of Aqua Cave reach 2.9 km, cavers were unable to follow the water any further towards Burnsville Cove. French Lake was always considered a key to the continuation of the cave. In recent years Ron Simmons has pushed the limits of French Lake, diving over 0.4 km into this sump.

GEOLOGY AND GEOGRAPHY

ANTHROPOGENIC CAVES IN ST. PETER SANDSTONE AT MINNEAPOLIS, MINNESOTA

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Farmers & Mechanics Bank Cave, a maze cave in the St. Peter Sandstone underlying Minneapolis, has been attributed by some authors to piping of the poorly cemented sandstone into the North Minneapolis Tunnel. This tunnel is the main sanitary sewer for the downtown area. The cave was discovered by tracing white sand carried by the sewer back to its source. A rusty well pipe reportedly found in the cave suggests that the cave initially was excavated by the hydraulic action of an artesian water well that flowed out of control. The time available to erode a void of this size, which underlies a city block, can be determined from the chronology. Construction of the tunnel began in 1889, while the earliest known record of the cave is a 1904 survey. In the sense that humans provided source and sink, the cave is not natural or artificial, but anthropogenic.

The case of Chutes Cave, also in Minneapolis, is more complex. The natural sandstone cave reportedly was discovered in 1866 during construction of a tunnel by the St. Anthony Falls Water Power Company. The cave was enlarged artificially as shown by pick-marks on the walls. The cave was sealed off from the Phoenix Mill tunnel, a water power tunnel to which it was connected, in 1874. Water leaked around the bulkhead, however, enlarging the cave to the extent that it caused Main Street to collapse on December 23, 1880. The cave, thus, appears to have all three components: natural, artificial, and anthropogenic.

THE NUMBER OF CAVES IN MINNESOTA

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Fillmore County has more caves than any other county in Minnesota. It is, therefore, surprising to note that state geologist Newton H. Winchell, in his 1884 *Final report on the geology of Fillmore County*, never once used the word cave or cavern, despite frequent reference to other karst features. A 1967 publication of the Minnesota Geological Survey stated that, within the outcrop area of the Galena and the Dubuque formations in Minnesota, "about 150 caves have been reported." A 1974 University of Wisconsin master's thesis mentioned "255 caves recorded in southeastern Minnesota." The *1980 NSS Convention Guidebook* stated that "Fillmore County contains over 300 known caves," while the 1995 geologic atlas of Fillmore County estimated "hundreds of caves—probably more than the rest of Minnesota combined." According to the Minnesota Karst Database maintained by Professor Calvin Alexander at the University of Minnesota, 196 caves have been assigned ID numbers in Minnesota as of the year 2000.

In January 2000, the Minnesota Speleological Survey produced a "Long Cave List" that listed 82 natural caves 30 m or more in length. From this data set, which includes geological data, it was calculated that 66% of Minnesota caves are found in the Upper Ordovician Galena Group and Dubuque Formation, including the longest, Mystery Cave, with a surveyed length of 20.21 kilometers. The second largest category contains maze caves in the Lower Ordovician Oneota Dolomite (16%). The third largest category is pseudokarst, containing caves in the Middle Ordovician St. Peter Sandstone (9%).

POLYPHASE MORPHOGENESIS OF THE LICK CREEK CAVE

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Lick Creek Cave (Little Belt Mountains, Montana) is formed within Mississippian carbonates of the Madison Group. Modern caves and paleocaves as old as late Mississippian are in the area. The cave follows roughly the contact between the Mission Canyon and Lodgepole formations via bedding plane discontinuities and sub-vertical fractures down-dip at 15°. At 250 m in from the entrance, the cave intersects sub-vertical fractures striking parallel to host rock. Cave morphology changes from conduits to an elongate chamber — Rain Room (60 m x 60 m x 20 m high), developed in sheared and fractured host rock. Beyond the fracture zone the cave passes into the breakout dome of the Cathedral Room (150 m x 200 m x 30 m high). The dome is partly filled with collapse leached host rock breccias.

Change of morphology to the massive dome of the Cathedral Room results from intersection and re-excavation of a paleocave. Evidence includes: 1. paleocaves in nearby outcrops; 2. contemporaneous leaching of older paleocave-fill breccias; 3. $C^{13/12}\delta$ vs. $O^{18/16}\delta$ data showing both host rock and paleocave-fill breccias equilibrating to the present meteoric regime; 4. the Cathedral Room ceiling typifies morphology expressed by a stabilized breakout dome, whereas the Rain Room's ceiling resembles unstable cantilevers.

The Lick Creek Cave's morphologies, in common with many caves, represent a complex amalgam of stratigraphic and structural controls through time. Re-excavation of a pre-existing paleocave has not been described in the literature regarding other caves in Madison Group Limestones.

MORE THAN ONE WAY TO SKIN A CAT: IS PUMPING FROM KARST FEATURES AN ALTERNATIVE TO PAYING FEDERAL RESERVOIR STORAGE FEES IN TENNESSEE?

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Recently the Corps of Engineers announced a "reallocation" plan to begin charging Tennessee industries, utilities, and municipalities for storing water in the TVA/Corps system of reservoirs. Facing costs of potentially millions of dollars, some users are considering pumping from caves, karst windows or wells near the reservoirs as an alternative to the storage fees. Can water users legally use this alternative when there is an apparent hydrologic connection between groundwater and the reservoir?

Statutory powers of the Director of the Tennessee Water Resources Division include "creating and defining the rights of respective competing users" of water resources. The statute is largely silent on what rules the director must apply. In an older Tennessee Appeals Court decision, pumping from a sinkhole was alleged to dry up a nearby spring. The court found "correlative" rights of the competing users that were not dependent on proof that the water flowed in a "well defined channel." The sinkhole owner was enjoined from pumping such quantities of water as might materially interfere with the spring owner's use. Under these rules a user should be allowed to pump some water but not enough to materially impact the reservoir.

The Corps might argue that federal law preempts Tennessee law. Preemption analysis is especially convoluted in this instance. The Corps sells storage space in its reservoirs. But federal law also requires that the storage space buyer separately obtain rights to the water stored under state law. Litigation will probably be needed to resolve the issues.

KARST GROUNDWATER BASIN MAPS FOR KENTUCKY

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About 55% of Kentucky is underlain by carbonate rocks that can form karst, and 25% of the state is underlain by mature karst. One characteristic of mature karst is a general absence of aboveground drainage. Because surface drainage is disrupted, predicting the boundaries of a karst groundwater basin is difficult. Knowing the boundaries of a karst watershed is essential for emergency response to contaminate spills, for managing water supplies, for mitigating nonpoint-source pollution, for determining the effectiveness of best management practices, and for budgeting scarce financial resources to improve groundwater quality.

The karst atlas program is an effort to develop maps depicting karst geohazards such as flooding, cover-collapse, and vulnerable groundwater basins. The first element of the atlas is maps depicting delineated karst groundwater basins. These maps are compiled from existing records or publications of groundwater dye traces by numerous researchers. The maps depict hydrologic features, the estimated path of groundwater flow, and the outline of the basin boundary.

Four groundwater basin maps have been completed at 1:100,000 scale. A fifth map is under revision and new maps are planned. They show the relationship between the surface catchment area and the spring to which the groundwater flows. The basin area for a spring may also be used to estimate the base-flow discharge of a spring to evaluate its potential as a water supply. The maps can also be used to determine the vulnerability of springs to pollution from existing or proposed land use.

GROUNDWATER QUALITY IN A KARST AQUIFER FOLLOWING BMP IMPLEMENTATION

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Water quality in the Pleasant Grove Spring karst groundwater basin, Logan County, Kentucky, was monitored to determine the effectiveness of best management practices (BMPs) in protecting karst aquifers. Of the 4,069-hectare watershed, 92% is used for agriculture. Monitoring began in October 1993 and ended in November 1998. By the fall of 1995, ~72% of the watershed was enrolled in Water Quality Incentive Program sponsored BMPs.

Pre-BMP nitrate-nitrogen concentration averaged 4.65 mg/L. Median total suspended solids concentration was 127.0 mg/L. Median triazines concentration was 1.44 µg/L. Median bacteria counts were 418 colonies/100 mL for fecal coliform and 540 colonies/100 mL for fecal streptococci. Post-BMP, average nitrate-nitrogen concentration was 4.74 mg/L. Median total suspended solids concentration was 47.8 mg/L. Median triazines concentration was 1.48 µg/L. Median fecal coliform count increased to 432 colonies/100 ml, but median fecal streptococci count decreased to 441 colonies/100 mL.

Pre- and post-BMP water quality were statistically evaluated by comparing annual mass flux, annual descriptive statistics, or population of analyses for the two periods. Nitrate-nitrogen was statistically unchanged. Increases in atrazine-equivalent flux and triazines geometric averages were not statistically significant. Total suspended solids concentrations decreased slightly, while orthophosphate concentration increased slightly. Fecal streptococci counts were reduced.

BMPs were only partially successful because the types available and rules for participation resulted in selection of less effective BMPs. Programs for the prevention of agricultural pollution of karst aquifers should emphasize installation of buffer strips around sinkholes, exclusion of livestock from streams and karst windows, and withdrawing land from production.

CAVES OF VALCOUR ISLAND, CLINTON COUNTY, NEW YORK

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Valcour Island is a limestone island on the New York side of Lake Champlain. The island contains small caves formed at or above lake level and much longer maze caves formed at or below mean lake level. The first group was first described by George Hudson in 1910. Some of these have undergone significant natural changes in the last 90 years and some can no longer be considered caves. These changes appear to be caused by a combination of wave and freeze-thaw action.

The second group was discovered in the last 10 years. These are network mazes that are similar in passage morphology to the large maze caves seen in the Watertown, New York, area. The passage cross-section is teardrop in shape with uniformly scalloped walls. The scallops are generally consistent in wavelength throughout the cross-section of the passage and show no asymmetry to indicate flow direction. These maze caves are proximal to the lake and no passage seems to extend more than 10 m from the lake. The farther from the lake, the smaller and lower the passages get. All of the longer caves found to date are in areas exposed to significant wave action. Despite searches, none of these longer caves have been found in sheltered coves and bays. It is proposed that these caves are formed by the dissolution of limestone by wave action moving water back and forth.

FRENCH BAY BRECCIA DEPOSITS, SAN SALVADOR, BAHAMAS: EVIDENCE FOR KARST GENESIS

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On San Salvador Island, Bahamas, 30 breccia deposits can be found along a more than 1-km length of sea cliffs in French Bay. These deposits have not been observed elsewhere on the island. The breccia deposits range from matrix to clast supported and consist of angular blocks of laminar-bedded oosparites within a red micritic matrix. These deposits have traditionally been interpreted as paleo-talus deposits from an eroding sea cliff of oxygen isotope substage 5e transgressive dune deposits. A January 2000 study was conducted to characterize several of the deposits, in an effort to develop a sequence of development. A survey of several deposits revealed a vertical restriction in development of +2 to +7 meters above sea level, which is consistent with flank margin caves developed during the post-transgressive substage 5e sea-level stillstand. The deposits are distributed in a "bead on a string" manner with globular morphologies, undulating bases and overhung lips in some inland locations. Petrographic analysis confirmed that the clasts and country rock are both laminar-bedded oosparites. Petrography of the matrix showed it to be unstructured, containing fine particulate detritus within micritic calcite cement. The caliche boundary displayed prominent layering and consisted primarily of layered micritic calcite. Survey, morphologic, and petrographic results show that the breccia deposits reflect qualities of a soil breccia in-filling breached flank margin caves.

THE ORIGIN OF NATURAL POTENTIAL ANOMALIES OVER CAVES

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Natural electrical potentials (NP) arise in the earth from a variety of sources. They are measured with non-polarizing electrodes, usually with one stationary reference electrode, and one electrode that is moved along a measured line. When the NP is measured over a cave, an anomaly is found that can be either positive or negative in polarity when compared to the background potential. These anomalies, shaped like a sombrero, are attributed to electrokinetic (EK) potentials resulting from the movement of water from the cave to the surface or surface to the cave. No direct experimental proof has been provided for this theory. The only indirect evidence offered has been to show that the other possible anomaly source, telluric currents, should have a different anomaly shape: an S-curve superimposed on a regional gradient. However, when both gradient-array resistivity and NP surveys are performed over the same area, they are shown to have very similar responses over the same areas. This includes both high- and low-resistivity anomalies. On NP surveys, the regional gradient from tellurics is too small to be seen above the noise, and the anomalies do not have the expected S-curve shape. Telluric anomalies similar in shape to those measured over caves also appear over high-resistivity areas where no underlying cavity or movement of water is present. Resistivity surveys have proven to provide more detailed results than NP surveys.

OBSERVATIONS OF TOWER KARST, PHANGNA-KRABI AREA, SOUTH THAILAND

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Recent observations of tower karst in Phangna Bay and inland in Krabi District, south Thailand showed several phenomena meriting further study. Despite consistent dips of 20°-25°, vertical to overhanging tower walls predominate. This apparently is due to strong vertical jointing, only a little of which is along the strike. Descent of profuse tropical rainfall along these and other joints has produced extensive vertical and near-vertical speleogenesis, deep open pits and broader karst windows, and some honeycombing. Subsequent collapse has exposed many longitudinal sections of caves, honeycombed towers, and cavernous fissures. Much of the dripstone and flowstone seen on tower walls was deposited in these cavities and weathered after exposure to the out-of-doors. Littoral niches are on some inland towers, and some niches at present sea level undercut into towers for more than 10 m. Collapse from this undercutting appears to contribute to development of some vertical tower walls.

NITER AND ANOTHER NITRATE MINERAL IN VIRGINIA CAVES

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The mineral niter was collected in Perry Saltpetre Cave on 24 February 1985 as part of a study of saltpetre mineralogy. The niter occurred as hair-like and lint-like fibers on the limestone wall. This was the only occurrence of any nitrate mineral found in the nine Virginia saltpetre caves studied in 1985-86.

On 27 January 1996, translucent acicular crystals were observed protruding from a sediment-floored crawlway in Mathews Cave No. 1. At the time, the outside temperature was in the teens (ºF) and the site of the occurrence was cold enough that one's exhaled breath was visible. The crystals had a cool but bitter taste and disappeared after an exhalation was directed their way. Translucent, lint-like crystal mats were observed in Powell Mountain Shelter Cave on 31 January 1996 and Powell Mountain Saltpetre Cave on 27 February 1996. Individual fibers were about a centimeter in length and tasted cool though bitter, but were unaffected by exhaled breath. Lint-like and straight acicular crystals, that cooled the tongue before bitterness but were unaffected by exhaled breath, were found in Ridge Cave on 18 March 1996. The lint-like efflorescent mineral in Powell Mountain Saltpetre Cave and both forms of the Ridge Cave mineral were collected and identified by x-ray diffraction as niter.

GEOLOGY OF FAIRY CAVE AND GLENWOOD CAVERNS, COLORADO

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The Mississippian Leadville Formation, a dolomitic limestone from 53-69 m thick, hosts Fairy Cave/Glenwood Caverns. The entrances are located a few hundred meters south of the summit of Iron Mountain, which is ~1 km northeast of Glenwood Springs, Colorado. The bedding at the cave dips ~20º to the south. The cave passages have been dissolved from the limestone by the mixing of two waters. One of these waters was near-surface water that percolated into the limestone from the White River Plateau. The other was deep-seated rising water that was probably very similar to the water that issues from the modern Glenwood Springs. Some speleogenetic features in Fairy Cave, such as iron oxide and manganese deposits and CO_2 bubble trails, are similar to those in Cave of the Winds near Manitou Springs, Colorado. Other speleogenetic features in Fairy Cave, including gypsum crusts, are more like those of Carlsbad Cavern or Lechuguilla Cave, and the modern Glenwood Springs have a significant sulfurous content. Apparently, whereas Cave of the Winds was formed mostly by CO_2 and the Guadalupe caves were formed mostly by H_2S, Fairy Cave was formed by a combination of both processes. A radiometrically dated basalt on nearby Lookout Mountain indicates that Fairy Cave was probably dissolved from the limestone over a period of a few hundred thousand years ~6 Ma ago.

URANIUM-SERIES AND PALEOMAGNETIC DATING OF CAVE DEPOSITS IN THE CHIQUIBUL SYSTEM OF BELIZE AND GUATEMALA, CENTRAL AMERICA

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Mature holokarsts around the periphery of the Maya Mountains of Belize and Guatemala are drained by regionally extensive caves. Highland rivers coalesce on granite and meta-sediments and drain into large cave conduit systems in heavily brecciated Cretaceous carbonates. Progressive abandonment has formed four or more levels of galleries in these caves, which have a surveyed extent of about 65 km. Extensive speleothem deposits are ubiquitous in the caves, as are allochthonous river sediments. Paleomagnetism of laminated clays was measured at several caves in the Chiquibul and Rio Grande regions of Belize in the late 1980s, but no magnetic reversals were noted.

In 1998-99, speleothems in the Chiquibul Cave System of Belize and Guatemala were sampled with U-series alpha dating. Uranium contents in this area were high (up to 1.5 ppm) and larger speleothems were sampled. Ages ranged upward from 18 ka BP, with one exceeding the alpha method limit (of 350 ka BP). Its U^{234}/U^{238} ratio of 1.16 suggests an age less than 1.25Ma BP, perhaps 780 ka BP based on assumptions of initial U-ratios.

The results of a simple linear correlation and regression generally support the intuitive hypothesis that higher levels should be of greater age and longer development. An approximate rate of uplift/stream incision for this interval sampled is about 1 m of vertical change per 10 ka, a rather moderate minimum figure. Coincidentally, this is similar to local regional solutional erosion rates of 100-130 m^3/km^2/year in several Belizean karsts, as determined through hydrochemical and runoff analyses.

AIR AND WATER CAVE TEMPERATURE VARIATION IN THREE CAVE TYPES IN GUAM, USA: IMPLICATIONS FOR AQUIFER CHARACTERISTICS

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Air and water temperature profiles were recorded in three cave types in Guam, USA: inland caves (Awesome and Pagat Cave), a coastal cave (Franks Cave) and a coastal fracture discharge cave (No Can Fracture). Temperatures were measured and recorded every fifteen minutes for a four day, and a two month period, using Hobo™ temperature data loggers.

Air temperatures can help determine if condensation corrosion is active, which would indicate cave volume is increasing over time in the vadose portion of the aquifer. Previous research suggested that the environment that may support the process is a wet cave where warm water underlies cool air, allowing for atmospheric instability. No such environments were found in the Guam caves, indicating no lifting mechanism is currently present to initiate air ascent necessary for condensation corrosion.

The diurnal cycle of water temperature in the coastal fracture discharge cave indicates low temperatures at low tide when the fracture is dominated by freshwater discharge, and high temperatures at high tide when warm lagoon water dominates the fracture. The depth of the halocline was determined by contrast in the percent of the time the temperature sensor is less than or equal

to 26°C, which is found ~1.5 m under the mean sea level. Only about half of the discharge from No Can Fracture is freshwater (0.2 mgd), indicating that mixing dissolution is currently active in the distal portion of the aquifer.

THE CARBONATE ISLAND KARST MODEL

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Tropical carbonate islands are a unique karst environment: 1) fresh water - salt water mixing occurs within the fresh-water lens; 2) glacioeustasy has moved the freshwater lens up and down through a vertical range of over 100 m; and 3) the karst is *eogenetic, i.e.*, it has developed in carbonate rocks that are young and have never been buried beyond the range of meteoric diagenesis. Carbonate islands can be divided into three categories based on basement-sea level relationships: simple carbonate islands (no non-carbonate rocks), carbonate cover islands (non-carbonate rocks beneath a carbonate veneer), and composite islands (carbonate and non-carbonate rocks exposed on the surface).

The Carbonate Island Karst Model (CIKM) synthesizes the geology and hydrology of carbonate islands into a coherent, unified concept. It can be visualized in terms of a three-dimensional framework, with island size on the x-axis, sea-level change on the y-axis, and bedrock relationships on the z-axis. The greatest degree of difference in carbonate island aquifer characteristics occurs in the transition from a small carbonate island to a large composite island. The CIKM can characterize island (and continental coastal carbonate) aquifer "trajectories" reflecting changes due to tectonic movement, glacioeustasy, or volcanic activity over time. Sea level change is the dominant controlling factor in carbonate island karst aquifers.

CAVE AND KARST DEVELOPMENT ON GUAM: IMPLICATIONS FOR AQUIFER HISTORY

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Guam is a tectonically active composite island located at the southern end of the Mariana archipelago in the Western Pacific. The island is divided into two major physiographic provinces: a northern limestone plateau with volcanic inliers, and a southern dissected volcanic upland with limestone outliers. Cave development on Guam occurs in both inland and coastal settings. Stream caves have formed at the limestone/volcanic contact at volcanic inliers such as Mt. Santa Rosa in the north, where they conduct water rapidly to the freshwater lens. Pit caves that act as vadose-bypass routes are present in limited numbers, and provide a rapid pathway for meteoric storm water to the lens. Flank margin caves, formed by mixing of fresh and saline water and now exposed by glacio-eustatic sea level fall and tectonic uplift, are concentrated mainly along the periphery of the northern half of the island. At sea level along rocky, cliffed coasts, fresh water flows from caves and dissolutionally enlarged fractures.

Glacio-eustasy and tectonic uplift have produced cliffs with numerous exposed notches, caves, and cave remnants. Notches are especially abundant. The notches appear polygenetic; some are fossil bioerosion features, others display morphologies similar to flank margin caves breached by cliff retreat and contain significant speleothems. If these latter features are truly remnant caves and not simply uplifted bioerosion notches, their size and spacing offer insight to the nature of the paleohydrology and development of the northern Guam aquifer.

MINERALOGY OF CAVE DEPOSITS ON SAN SALVADOR ISLAND, BAHAMAS

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San Salvador Island, on the eastern edge of the Bahamian Platform, is the location of a large number of relatively small flank margin caves. In addition to the more obvious speleothems - stalactites, stalagmites, and flowstone - the San Salvador caves contain a variety of crusts and soils of unknown mineralogy. Speleothem samples from ten caves in the northeastern and southwestern corners of San Salvador Island were analyzed by means of X-ray diffraction, scanning electron microscopy, and the electron microprobe. In addition to the prominent calcite, aragonite, and gypsum already known to occur in San Salvador caves, eleven other minerals were identified. The minerals are celestite, $SrSO_4$; cesanite, $Na_3Ca_2(SO_4)_3OH$; ardealite, $Ca(HPO_4)(SO_4)\cdot 4H_2O$; brushite, $CaHPO_4\cdot 2H_2O$; hydroxylapatite, $Ca_5(PO_4)_3OH$; fluorapatite, $Ca_5(PO_4)_3F$; chlorapatite, $Ca_5(PO_4)_3Cl$; collinsite, $Ca_2(Mg,Fe)(PO_4)_2\cdot 2H_2O$; whitlockite, ß-$Ca_3(PO_4)_2$; niter, KNO_3, and nitratine, $NaNO_3$. Cesanite has not been previously reported from a cave. This is the second reported occurrence of collinsite. Previous isotopic work indicates that the sulfate in San Salvador caves results from a combination of infiltrating sulfate from sea spray, and oxidation of biologically mediated sulfur from anoxic zones in the freshwater lens. The phosphate minerals are a complex outcome of the interaction of bat guano, freshwater, seawater, and desiccation, acting in a variety of sequences.

AN OVERVIEW OF THE SAN ANTONIO SEGMENT OF THE EDWARDS (BALCONES FAULT ZONE) AQUIFER IN SOUTH-CENTRAL TEXAS

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The San Antonio Segment of the Edwards (Balcones Fault Zone) Aquifer is located in south-central Texas and includes portions of Kinney, Uvalde, Medina, Bexar, Comal, and Hays counties. The Edwards Aquifer is the sole source of water for over 1.5 million people, including the city of San Antonio. It is extensively used for crop irrigation and is the source of water for the two largest springs in the southwestern U.S.: Comal Springs and San Marcos Springs. Geologically, the aquifer occurs in the Cretaceous Edwards Limestone, which is extensively faulted and fractured. Groundwater is contained in dissolutionally enlarged fractures and bedding plane partings.

The Edwards Aquifer has many management challenges. Over 450,000 acre feet of water have historically been withdrawn from the aquifer from some of the highest yielding wells in the world. More than 100 wells have no measurable drawdown, some with pumping rates that exceed 5,000 gpm. In addition, the aquifer is the home for at least 44 unique species. Continued development over the aquifer's recharge zone, coupled with transportation routes that cross the region, have also presented environmental challenges to protect water quality.

The Edwards Aquifer Authority has been mandated by the Texas Legislature to manage, conserve, preserve, and protect the Edwards Aquifer. Pursuant to this mandate, the Authority has undertaken a series of 17 interrelated "optimization" studies over the next 8 years at an estimated cost of more than $6 million. These studies are designed to obtain the necessary data to better manage the aquifer.

IMPERVIOUS COVER LIMITS: IMPLICATIONS FOR PROTECTING AND MANAGING WATER QUALITY IN KARST AQUIFERS

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Managing the impacts of urbanization on water quality has typically relied on regulating development activities in watersheds. This is complicated and sometimes ineffective due to the variety of contaminants and their often unexpected sources. During the past 10 years, nationwide studies have examined the water quality impacts of impervious cover — impermeable non-natural surfaces such as buildings, roads, and parking lots. The summary results are that watersheds with more than 10-20% impervious cover (usually 10-15%) suffer significant degradation in water quality, biodiversity, and other parameters, and demonstrate that impervious cover can be used as a general measure of impact and an easily regulated means of watershed protection.

The impacts of impervious cover on groundwater quality have not yet been rigorously studied. Given the often analogous behavior between karst aquifers and surface streams, a similar relationship should exist, and was tested in a hydrologically distinct part of the Edwards (Balcones Fault Zone) Aquifer, in San Antonio, Texas. Impervious cover was estimated with land use data for the 200 km^2 study area and comprised 16.4% of the total. This result

suggests the area is on the threshold where significant groundwater contamination should begin to occur and is supported by the presence of recent anthropogenic contaminants in the aquifer. Maintaining impervious covers to less than 15% of a groundwater drainage basin may be effective in preserving karst groundwater quality, if combined with avoidance of critical recharge areas and prohibition of landfills and industries that are incompatible with water quality protection.

GEOMICROBIOLOGY

MICROBIAL LIFE IN THE UNDERWORLD: BEYOND THE HYP(OTHESES)

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There is a clear physiological distinction between the types of microbial life expected to be found in caves. "Chemoautotrophs" use the chemistry of the cave environment for energy production, and as such may play a role in speleogenesis. "Heterotrophs", on the other hand, feed on the chemoautotrophs and/or organic debris that enters the cave. As a result, caves can be divided into two separate environments, the organic and the geologic.

The geologic cave environment is a hard, starved landscape for life. Without light, organisms must make their living riding the thermodynamic gradients of chemistry in order to generate energy. However, in caves, the environment is essentially oxidized, providing little in the way of chemical energy. Perhaps the greatest contribution of cave-microbiology is, therefore, not simply the identification of new species, but how these organisms fit into the complex, nutrient-sparse landscape of the cave and generate enough energy for survival. The potential results could identify significantly diverse communities in the three-domain tree of life.

The Deep Biosphere is a term often used to describe microbial life not confined to the surface, but continuing for kilometers into the Earth's mantle. While it is thus not surprising to discover that caves may also contain communities of microorganisms, it is important to maintain perspective on the abundance, role and significance of these organisms in speleogenesis and the development of secondary formations. Scientists must remain wary of placing a 'microbial' tag on any structures that are not yet fully understood, and continue to evaluate results critically.

A GARDEN INSIDE OUT: MICROBIAL MATS IN SPRINGS, WALL MUDS, AND CEILING FORMATIONS OF A SULFUR-DOMINATED CAVE, CUEVA DE VILLA LUZ, TABASCO, MEXICO

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We have recently discovered dense microbial mats lining springs in sulfide-dominated Cueva de Villa Luz, Tabasco, Mexico. Within the same cave, oddly patterned muddy wall deposits are spongy microbial mats held together by slime. Microbial strings dangle from ceilings and gypsum crystals. Other materials also contain abundant microorganisms. Indeed, the cave literally drips and oozes with a fantastic microbial garden.

Water and gases flow into the cave from numerous springs. Hydrogen sulfide concentrations up to 204ppm, CO to 110ppm, and oxygen as low as 9.5% has been measured near springs. SO_2, CO_2, COS, and formaldehyde have also been detected.

Microbial mats contain S_o and gypsum forming *in situ* (SEM/EDS). TEM reveals several organism morphologies. Mat patches exhibit auto-fluorescence under UV and pink or green by visible light. Isolates include sulfate-reducing bacteria, thiosulfate metabolizers, and sulfur users. Wall mudmats contain clumped cells (primarily short rods) embedded within the mud matrix. Both autotrophic and heterotrophic organisms have been isolated on selective media. Rubbery microbial slimes suspended from ceilings and formations are dominated by *Thiobacillus* and tiny gypsum crystals. Water dripping from the tips exhibit pHs as low as 0.3.

Numerous midges, spiders, other invertebrates, fish, and bats (an unusually great abundance) appear to be dependent upon the hydrogen sulfide and microbial processes that use it. Other non-sulfur caves in the region and non-sulfur areas of the same cave do not show the biological richness of the sulfur-impacted areas.

BACTERIALLY INDUCED PRECIPITATES: LABORATORY PRODUCTS & NATURAL

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Bacteria fossils are preserved as soft tissue, mineralized casts, molds, etc. Unfortunately, preservation potential for bacterial bodies is poor. In the lab, bacteria have been observed to burst and collapse within a few days after entombment in mineral matter. Thus, their former presence commonly is indicated by an abundance of micron-sized pores rather than preserved body fossils. Evidence that the micropores represent decayed bacteria is their size, spatial relationships, and the epifluoresence indicative of the presence of remnant organic matter. Additionally, distinctive organic compounds have been recognized and their presence indicates the former existence of bacteria.

Fortunately, bacteria have the ability to induce the precipitation of many different minerals, e.g., calcite, aragonite, dolomite, as well as Fe-, Mn-, and K-rich precipitates. In the lab, precipitates occur as individual crystals, crystal bundles (rods, spheres, dumbbells, disks, rhombohedra, tetragonal dipyramids, etc.), and as solid crusts. In the rock record, the best documented bacterially induced precipitates take the form of silt- to fine sand-sized round to elliptical mineral aggregates around clumps of bacteria (e.g., peloids in coral reefs) and shrubs or bushes (hot water travertines). Laboratory experiments as well as comparisons with natural deposits strongly indicate that cyanobacterial mats are lithified into stromatolites due to the bacterially induced precipitation.

Demonstrating the bacterially induced origin of a deposit in nature is best accomplished by an accumulation of characteristics, i.e., essentially, there is no one definitive piece of evidence.

FIRST DIVES INTO KAUHAKO CRATER LAKE, KALAUPAPA, MOLOKAI, HAWAII: A DEEP VOLCANIC VENT DOMINATED BY MICROBIAL LIFE

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Kauhako Crater Lake is the only deep lake on the Hawaiian Islands. It is situated on the Kalaupapa Peninsula of Molokai and represents the central vent of the Kauhako shield volcano. The depth of the lake is in excess of 250m (Maciolek 1982). In March 1999, we (S.K.) conducted a first water sampling program (down to 150m) and confirmed the existence of a very stable pycnocline, which separates the shallow oxygenated surface layer (15 ppt salinity) from the deep anaerobic bottom layer (32 ppt salinity). We discovered widespread carbonate deposits along the perimeter of the lake, protruding shelf-like at a depth of ~.20 cm. In March 2000, we (M.G. & S.G.) started to dive the lake. Three dives, using advanced cave diving techniques, were conducted, the deepest down to 123m. These dives resulted in the discovery of further carbonate deposits on the walls of the vent beneath an ubiquitous and highly structured microbial mat, which covered all surfaces of the vent wall below the pycnocline. The mat is partly composed of sulfate reducing bacteria. Their action causes the alkalinity to increase to above 10 meq/l (seawater 2.3 meq/l). When mixed to the surface layer, this excess alkalinity leads to a high calcium carbonate saturation causing microbially mediated non-enzymatic calcium carbonate precipitation. A system like this is called an "alkalinity pump" and is important for the understanding of stagnating oceans as occurred in the geologic past (Kempe & Kazmiercza, 1994).

EARTH'S BASEMENT BIOSPHERE: EXPLORATIONS OF AN ANCIENT, RADIOGENIC WILDERNESS IN THE DEEP LEVELS OF AFRICAN GOLD MINES

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In recent years, the phylogenetic diversity and spatial distribution of the known microbial biosphere have proven far in excess of what traditional views would allow. Due in part to persistent difficulties in obtaining appropriate samples, the ultimate depth limit for subterranean microbial life remains uncertain. The Witwatersrand Au mines of South Africa, now penetrating to depths of more than 4 km, represent mankind's deepest excavations and possible windows into the deep continental subsurface biosphere. In 1998 and 1999, a multidisciplinary team assembled by Princeton University conducted an ecosystem-level characterization of strata intersected by mines owned by Gold Fields LTD. The team sampled rock and fissure waters using chemical, particulate and microbial tracers to differentiate potential indigenous life signatures from process-derived contamination. Indications are that the subsequent laboratory follow-up reveals wide-ranging microbial communities, diagnostic of a labyrinthine web of groundwater conduits generated within the impermeable country rock by dyke intrusions and faulting. Among the diverse forms encountered, DNA sequences related to known hyperthermophilic archaea were obtained from some of the deepest and hottest fissure waters. Overall, DNA and molecular biomarker analysis, cultivation and stable isotope characterizations all indicate that life does likely persist in this extreme environment to depths exceeding even those accessible by ultra-deep mining.

MICROBIAL INTERACTIONS IN PUNK ROCK AND CORROSION RESIDUES IN LECHUGUILLA CAVE, CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

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Walls and ceilings of Lechuguilla and Spider caves show extensive deposits known as "corrosion residues" (CRs). These CRs may be colored black, gray, pink, orange, red, or ocher and are distributed throughout Lechuguilla and nearby Spider Cave. Geologists have hypothesized that Lechuguilla's extensive CRs are the long-term result of upwelling corrosive air, but the widely distributed presence of microorganisms has led us to investigate the possibility of microbial involvement in the dissolution of the wall rock. Bulk chemistry and XRD studies demonstrate that CRs are not simply dissolution products, but are highly enriched in certain elements such as Fe and Mn, possibly by microbial processes. Bacterial forms have been detected in both CRs and in the corroded "punk" rock beneath them, and metabolic activity studies demonstrate the presence of actively respiring cells.

In order to more fully characterize the microbial community associated with corrosion residues (CRs), our team is utilizing molecular phylogenetic techniques. Results from the phylogenetic analysis of the small-subunit ribosomal RNA (rRNA) gene from clones shows that the nearest relatives of several of the clones are *Crenarchaeota*, iron-oxidizing bacteria, gram-positive bacteria, nitrite-oxidizing bacteria, and actinomycetes. Most of the sequences are very dissimilar to any other known 16S rDNA sequences. Identification of novel organisms within this low-nutrient environment may give us insight into the unusual microbial communities which inhabit these immense cave systems.

POTENTIAL BIOSIGNATURES IN CAVES: MN-MINERALS IN LECHUGUILLA CAVE, NEW MEXICO

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We often observe microorganisms in intimate association with cave minerals. Some mineral properties are impacted or even created by microbes. Biosignatures (physical, geochemical, or isotopic traces) are left behind. Some biosignatures are apparently formed *in situ* with living organisms rather than during later preservational stages. Lithified structures, tantalizingly similar to living forms, have been found both in our study caves and others. We have observed apparent transformation of living forms to lithified structures without cellular remains but retaining mat or biofilm morphology.

Of particular interest, Lechuguilla and Spider Caves at Carlsbad Caverns National Park, NM, contain Mn- and Fe-rich (up to 20wt% MnO) "corrosion residue" on many surfaces. Microorganisms exhibiting high respiratory activity (12-32 % of visually detectable cells) are ubiquitous in residue. Some residue with particularly interesting microscopic and macroscopic properties actively rains from the ceiling of a passage. SEM examination reveals irregular platelets woven together by filamentous strands of Mn-oxides. Individual platelets also consist of interwoven filaments. EDS analysis shows predominance of Mn, Ca and O and lesser amounts of K, Zn, and Pb. High resolution TEM imaging indicates poorly crystalline and mostly amorphous Mn-oxides. Filaments display a clear ribbon-like alignment of manganese-oxide coordination octahedra. The elemental composition, arrangement of the octahedal ribbons, and lattice parameters from 0.28 to ~1.0 nm are consistent with todorokite. We are attempting to discern whether this material is a result, at least in part, of biological activity as the presence of quadravalent Mn may indicate.

HISTORY

OVER 30 YEARS UNDER THE SINKHOLE PLAIN

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Binkleys Cave, under the sinkhole plain (part of Mitchell Plain) south of Corydon in cave-rich Harrison County, is Indiana's longest surveyed cave, currently at 34.7 km. Some of the water has been dye traced to Harrison Spring, the largest in the state. The cave was discovered around 1940, when a sinkhole pond opened up. From 1958 to 1962, the BIG (Bloomington Indiana Grotto) surveyed 10.4 km of passage. A few cavers, inconsiderate of the property owner, caused the cave to be closed for a few years. On Thanksgiving weekend 1967, a core of local cavers, calling themselves the Indiana Speleological Survey (ISS), resumed surveying where the BIG had stopped. The ISS charted new areas almost immediately, and soon pushed the survey to over 25 km by the early 1970s. Discovery and surveying has continued on and off since then, with the core of cavers being several of the original ISS (although the ISS is not maintained as an official group) cavers that started in 1967 having been involved in the project for over 30 years! In December 1999, a major upstream cave river was found, netting over 1.6 km of virgin cave. This was the culmination of a digging project that started in 1996. Many going leads remain, and the ISS cavers potentially have more kilometers of cave to survey. Water and biological studies show that the cave is threatened by urban development on the sinkhole plain.

THE CAVES OF MUSHROOM VALLEY, ST. PAUL, MINNESOTA

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A 3 km reach of the Mississippi River gorge near downtown St. Paul, Minnesota, is known locally as "Mushroom Valley" because of the abundance of man-made mushroom caves in the sandstone bluffs. Mushroom growing lasted a century, from its introduction by Parisian immigrants in the 1880s until the last cave ceased production in the 1980s during the creation of Lilydale Regional Park. Notable examples are Altendorfer, Bisciglia, Lehmann, and Peltier caves.

Some of the ~50 caves originated as sand mines, and not all were used for mushroom growing. Examination of city directories and Sanborn insurance atlases revealed that other common uses were aging of cheese (Land O' Lakes), lagering of beer (Yoerg's Brewery), and storage (Villaume Box & Lumber). The University of Minnesota rented caves in the 1930s for experimental ripening of blue cheese. A cave used by the St. Paul Brick Company later was gated as a bat hibernaculum by the Minnesota Department of Natural Resources. Mystic Caverns and Castle Royal were underground nightclubs in the 1930s, the latter hosting the Howdy Party for the 1980 National Speleological Society Convention.

The caves were surveyed during a civil defense study in the early 1960s. The typical cave is a straight, horizontal passage 50 m long, but often connected by cross-cuts to similar caves on either side, creating network mazes with multiple entrances. A cave operated by the Becker Sand & Mushroom Company is the largest of all, with 10 m ceilings and more than a kilometer of passages.

MINNESOTA SHOW CAVES

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The following is a list of the known show caves of Minnesota in chronological order, together with years of operation. All are either natural caves or artificially enlarged natural caves. The assistance of Gary K. Soule is gratefully acknowledged.

1. Fountain Cave, also known as New Cave and Spring Cave (St. Paul, MN, 1852-1857?).
2. Chutes Cave, also known as Nesmith Cave (Minneapolis, MN, 1875-1883).
3. Jesse James Caves, also known as Seven Caves (St. Peter, MN, 1929-1954).
4. Catacombs of Yucatan, also known as Black Hammer Cave (Spring Grove, MN, early 1930s).
5. Niagara Cave (Harmony, MN, 1934-present).
6. Old Mystery Cave (Spring Valley, MN, late 1930s-1942).
7. Wolfe Brewery Caves (Stillwater, MN, 1945-present).
8. Mystery Cave (Spring Valley, MN, 1947-present).
9. Minnesota Caverns, now the Mystery II entrance to Mystery Cave (Spring Valley, MN, 1960-present).
10. Hiawatha Caverns (Witoka, MN, 1964-1966).
11. Spring Valley Caverns, formerly Latchams Cave and International Caverns (Spring Valley, MN, 1968).

THE HISTORY OF WINDELER CAVE

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During mining operations in 1946, Windeler Cave was discovered, and in 1952, the cave was filled in under unexplained circumstances. After 20 years, the Diablo Grotto reopened the cave and they since have managed it.

Prior to 1946, Windeler Cave did not have a natural entrance. The cave was discovered by Charlie Windeler and other miners, and they permitted the now defunct Stanford Grotto to explore the cave in the years 1950-1952. The entrance gate has been broken into several times.Windeler Cave has been surveyed to 900 m and is unique to the Mother Lode area because of its many speleothems and pristine condition.

During the management of Windeler Cave, the Diablo Grotto has had to patrol, use electronic surveillance equipment, redesign gates, go to court to prosecute two vandals who were charged under the 1977 California Cave Protection Law, and fill in the entrance. Much of the problem has been traced to a person who wrote a fantasy of words and sold to many that were interested in seeking out their fortune in the era of high gold prices.

Scientific exploration was attempted, with Dr. William Elliott labeling one small water creature after Windeler. One of the limits in exploring Windeler was the requirement of electric lights, which studies were to be coordinated on, but this only led to vandalism by some of those who broke in during the '70s.

IDENTIFICATION AND ANALYSIS OF A CIVIL WAR SOLDIER'S NAME IN SOUTH CARTHAGE CAVE, TENNESSEE

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In May 1999, a possible Civil War inscription was found in South Carthage Cave. On a return trip, an intensive visual inspection was inconclusive, so photographs of the inscription were made. These were later examined electronically using exploratory data analysis, which revealed additional information and resulted in a positive identification. The inscription was made by John C. Reed of the 11th Ohio Infantry. Subsequent research indicates that Reed had a spotty military record and that he visited the cave between March 20 and June 4, 1863 while encamped near South Carthage. Reed's cave trip confirms that Union soldiers visited more caves, including relatively unknown caves, than previously suspected, and that American patterns of interactions with the cave environment persisted in the Civil War, despite the dislocations of the period.

EDMUND RUFFIN AND THE CYMBEE OF WOODBOO

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Edmund Ruffin was a noted 19th century agricultural reformer from Virginia as well as a staunch supporter of slavery. Civil War enthusiasts may remember him best as the individual who was selected to fire the first shot on Fort Sumter, South Carolina, thus beginning the War Between the States. Less known, perhaps, are Ruffin's antebellum speleological endeavors. In 1843 at the request of Palmetto State governor, James Hammond, Ruffin spent 8 months conducting an intense agricultural and geological survey of South Carolina. Much of his time was spent in locating limestone and marl deposits, which he felt could be used wisely for agricultural purposes. During his field work, Ruffin turned up interesting caves and karst features within the state. He described these in detail in his private diary. While visiting and talking with some of the locals, he was also introduced to a bit of folklore concerning the legendary inhabitant of a particular karst spring. This was a peculiar supernatural being or water sprite that the local Negroes called "the Cymbee of Woodboo".

CATTLE CAVE: HISTORIC ARCHIVE

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Cattle Cave in Lee County, Virginia, was mined for saltpetre. Civil War era writings on mattock marks in sediment contain more detailed inscriptions than just the names of miners. The most stirring sentiments were the following: "Nathan S. Cox Was born January 2nd 1842 This the 6th day of March 1862. Age 20 years 2 months & 4 days War is upon us But we will not be subjugated We will fight them as Long as there is a woman or little boy large Enough to raise a gun to fire Huzza Huzza Jeff Davis & the southern confederacy Nathan S. Cox Thursday Eve 1862." He served in the 50th Virginia Infantry and survived the Battle of the Wilderness and the war. A younger brother, Mitchel C. Cox, age 17 years 9 months and 6 days, recorded his thoughts during that March 6th evening. He served in the 64th Virginia Infantry and was captured at Cumberland Gap, exchanged as a prisoner, and served again before he was "Murdered and robbed in Russell Co., VA on 8/4/64." A sister, Mary A. F. Cox, and her friend, Cynthia Ann Pruett, also inscribed the sediment bank that March evening. Cynthia married another Cox brother in February 1865. A partially obliterated name dated 1860, may be that of General Creech. He enlisted the same day as Mitchel Cox and was captured at Cumberland Gap. Sent to Camp Douglas, he was held until he died of endocarditis on December 19, 1864.

DISPROVING A NEGATIVE: THE ALLEGED BLIND CAVE FISH FROM PENNSYLVANIA NEVER EXISTED

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In 1864, Edward Drinker Cope published a report on what he thought to be a new species and genus of troglobitic (blind, depigmented) cave fish, from Pennsylvania. As late as 1986, some authors, based on Cope's article, have continued to assume that there are troglobitic fishes in that state. Our study of the historical, biological, and speleological evidence failed to provide any evidence that such fish exist or ever existed. The original unsubstantiated reports seem to be based on the assumption that you cannot prove a negative, i.e., that we cannot prove that something does not exist just because we have not found it.

THE CAVEFISH CALENDAR: ESTABLISHING THE PRECISE CHRONOLOGY OF EARLY DISCOVERIES OF CAVE FISHES

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The history of the discovery of the first true troglobitic (blind, depigmented) fish has been unclear. Different claims have been made at different times about the primacy of discoveries in this area. There are at least three references for European cave fishes for pre-Linnean times: Besson (1569), Kircher (1665), and Montalembert (1748). All these citations are unsupported by scientific evidence and may have been based on uncritical observations. Even if they were true, they would all be preceded by a description of a cave fish in China in 1541 that seems to refer to a true cavernicole.

PALEONTOLOGY

THE SABERTOOTH CAT *SMILODON* FROM WEST VIRGINIA CAVES

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Remains of the Pleistocene sabertooth cat, *Smilodon*, are known from Hamilton cave in Pendleton County and Organ Cave in Greenbrier County, West Virginia. In Hamilton Cave, there are three associated lots of bones and teeth representing two different species of *Smilodon*. One lot consisting mostly of teeth and foot elements, represents *Smilodon gracilis*, while two other lots are of a larger species *Smilodon* cf. *fatalis*. Based on associated rodents, the age of the Hamilton finds is about 800 ka BP, though the individual localities may differ in age by as much as several tens of thousands of years.

The Organ *Smilodon* are more fragmentary. At one locality there are just two canine fragments, while at the second there are several tooth crowns and parts of others, as well as a few foot elements and many bone fragments. A carbon 14 date of 21040 ± 760 years was obtained from the second site, indicating a late Pleistocene age.

THE PLEISTOCENE FAUNA FROM EARLYS CAVE AND EARLYS PIT, WYTHE COUNTY, VIRGINIA

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Fossil bones and teeth were first reported from what is believed to be Earlys Cave, Wythe County, Virginia, by E.D. Cope in 1867. Cope reported the remains came from 2 places close together and one about 5 km away. Cope named 2 new genera and 5 new species from these remains, none of which Guilday, in 1962, considered to be valid. Part of Cope's collection still survives including teeth of *Equus* and *Tapirus*.

Recent investigation of Earlys Cave revealed pick marks believed to be those left by Cope. Additional breccia containing bones and teeth was recovered and treated with acetic acid to recover small species. At Earlys Pit adjacent to Earlys Cave no signs of earlier excavation were seen, but additional vertebrate remains were recovered, including three *Equus* teeth.

Species recovered included some of those noted by Cope, though *Equus* sp. was the only extinct species. Additional species not noted by Cope include *Sorex* sp., *Eptesicus fuscus*, *Clethrionomys gapperi*, and *Synaptomys borealis*. *Microtus* teeth recovered seem to represent a modern species, probably *Microtus pennsylvanicus*. It seems likely that the Earlys Cave and Earlys Pit faunas are late Pleistocene in age rather than middle Pleistocene, as suggested by Hay.

UPDATE ON PALEONTOLOGICAL INVENTORY OF CAVES OF MAMMOTH CAVE NATIONAL PARK, KENTUCKY, USA

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The Mammoth Cave Paleontological Inventory is a cooperative study of the vertebrate paleontological remains and deposits in caves of the Mammoth Cave National Park being conducted by The Illinois State Museum, the National Park Service and the Cave Research Foundation. The project is in its third year.

Within the caves, significant and potentially significant paleontological remains and deposits occur within four general contexts: 1) relatively recent (<4000 year old) remains on the surface in the cave; 2) relictual deposits representing the cave surface that had accumulated before the time humans began using the cave; 3) older surface deposits (such as guano accumulations). These are often found preserved under large fall blocks and sometimes under grainfall accumulation deposits; and 4) very old (hundreds of thousands to millions of years) deposits associated with primary, water-laid sediments in the cave.

Notable finds during the project include: a deposit containing an extinct vampire bat (*Desmodus* sp.); extensive ancient free-tailed bat (*Tadarida* sp.) roosts; and important information about the historic use of the caves by colonial bats, particularly Indiana bats (*Myotis sodalis*).

PHOTOGRAPHY

LOW-AIRSPACE CAVE PHOTOGRAPHY: SOME EXPERIMENTAL RESULTS

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Low-airspace cave passages can present quite interesting problems such as flood hazards, exploration challenges, and psychological barriers. They also present many photographic opportunities and challenges. The scene is usually stark: ceiling, caver, and water. The field of view tends to be limited, which makes it difficult to convey the length and breadth of the passage. But caver subjects are often up-close and personal, with expressions and emotions visible to an unusual degree. So successful photos can be evocative of environment and mood, leading viewers to thrill or shudder.

The environment demands both techniques and technology. Photographer and subject must be non-hypothermic. Gear needs to be waterproof and rapidly clearable. Fog management is a significant challenge. Successful results have been obtained using a point-and-shoot (PAS) camera (Nikon ActionTouch) and bagged, slaved strobes. PAS is fast and simple compared to Nikonos, and bulbs do not have to be reloaded. But there are significant problems with controlling exposure, and the best results are impossible without exposure bracketing. This is a particular problem with bounce lighting, which is highly desirable for producing a soft glow around water and caver.

RESCUE

THE POCKET MEDICAL KIT

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Getting a caver to carry a medical kit is usually an uphill battle. Most cavers will not carry a bulky, heavy medical kit when the space could be utilized by something "useful" - like extra survey gear. This guarantees that the caver will not have a medical kit on hand when it is most needed. A smaller, lighter kit is needed if we expect cavers to carry it.

One alternative to a regular medical kit is the "pocket medical kit". This is composed of several small and inexpensive items - duct tape, safety pins, zip top bags and gauze. All of these items can be stuffed into an area smaller than the palm of one's hand, and weigh only a few ounces. By focusing on the physical characteristics of each of the items (vs. the functional characteristics), the caver can develop the mind set needed to improvise several pieces of medical equipment. The caver can create sterile "gloves", splints, an irrigation syringe, wound closure strips, an occlusive dressing, and even a flotation aid.

HARNESS HANG SYNDROME: FACTS AND FICTIONS

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There are some myths about Compression Avascularization/RePerfusion Syndrome (CARP), also known as Harness Hang Syndrome. These myths distract cavers from the fact that this is a medical emergency and that most cavers are unable to deal with it as they consider the pickoff an unnecessary skill.

Originally, members of the French Speleological Society suspected that some caver fatalities attributed to exposure might have been caused by something else. The group undertook informal experiments where volunteers hung limply in harnesses. The volunteers quickly became ill so testing stopped. Later, the group pursued formal, controlled testing so that volunteers' vital signs could be monitored. The testing showed that hanging immobile in a harness caused problems in as little as ten minutes. They tested numerous harness designs and various body positions but the results were all similar. Recently, testing done by a German industrial safety group showed similar results from hanging immobile in a full body harness.

CARP Syndrome occurs when a person hangs in a harness and the venous blood in the legs is unable to return to the torso while arterial blood continues flowing downward. The result is identical to hypovolemic shock. Even if the subject is released within ten minutes, there may be additional complications caused by reperfusion of the legs. Like shock, CARP Syndrome is difficult to treat in the field and must be prevented by rescuing any caver hanging immobile on rope.

USE OF A "JIGGER"

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During any rope rescue raising and lowering process, a variety of problems can occur. These might include locked off prusik hitches, orientation of a litter, or the need to shift a load from one place to another. All these tasks can be accomplished efficiently using a compact jigger that is convertible from 4:1 to 5:1 or 9:1.

SURVEY & CARTOGRAPHY

WAKULLA 2 EXPEDITION—3D MAPPING

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During the 3 month Wakulla 2 Expedition, a total of 10 million wall points were imaged within Wakulla Spring, FL (averaging ~100 m water depth). The total distance of passage that was digitally imaged was 6409 m, however, multiple passes were make through the same passages. Mapping missions resulted in traversing 21,256 m of passage.

The Digital Wall Mapper (DWM) was designed and built for this expedition and has 32 sonar transducers spiraled around the front end, which measure the distance to the walls 4 times/second. An inertial measurement unit keeps track of the location of the mapper using ring laser gyros and accelerometers. Nickel metal hydride batteries power the electronics as well as the motor that propels the unit through the water. The DWM is ~2 m long and weights ~150 kg. It is neutrally buoyant and balanced to rest horizontally in the water.

The sonar produced a dense, precise image of the passage walls with detail unavailable through traditional forms of survey. The ring laser gyros accurately recorded angular changes by the DWM. The accelerometers built up error and mapping paths were significantly corrected by 38 cave radio locations. Additionally, passage locations were adjusted by matching sonar profiles.

The point cloud of wall points makes a complete map as is. However, the next step is to mesh the points into polygons to form solid walls and permit digital fly-throughs of the cave.

REFLECTORLESS TOTAL STATION SURVEY AND THREE DIMENSIONAL MODELING OF LICK CREEK CAVE

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Reflectorless Total Station high precision survey technique was used to survey the ceilings and breakdown piles in the Rain and Cathedral Rooms in Lick Creek Cave, Cascade County, Montana. The survey employed a single baseline of 57.691 m in the horizontal plane, by 26.743 m in the vertical plane and utilized a single total station closure technique for stations referenced to the defined baseline. Point data were collected at ~5° intervals. A pseudo-random data collection technique was employed to normalize the differential distribution of sample point densities collected using the semi-systematic method. Horizontal and vertical circle closures for control network stations were within 3mm +2ppm making Least Squares Adjustment of loops unnecessary. Visualization of room geometries employed Delaunay Triangulation minimum distance algorithm based sub-routines in both Matlab 5.1® and Arc/Info 7.6®. Triangulated irregular networks (TIN) were created for both ceiling and breakdown pile geometries. From the TINs, plan view contour maps were rendered in Arc/Info 7.6 and three dimensional volumetric representations were rendered using a grid normalization and iterative smoothing algorithm employed in Matlab 5.1. The resulting models accurately represent the rooms' macromorphologies. Employment of the technique facilitates the survey and volumetric representation of large cave rooms, and shows promise for near real-time three-dimensional mapping of cavernous karsts.

CARTO, A SOFTWARE TOOL FOR CAVE CARTOGRAPHY

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Carto is a tool intended for use by a cave cartographer. It is primarily intended to allow the preparation of conventional two dimensional maps in electronic form. The program has two main parts, a morphing system and a cad system. The morphing system takes as input processed survey data and scanned images of the in-cave sketches. The user marks the points on the image that correspond to stations and the program stretches the image so that the stations appear at their surveyed positions. Superimposing the morphed images produces a composite sketch that can serve as a working map. The cad system can then be used to "trace" over the sketch with standard map symbols, as well as user defined symbols. The cartographer can then experiment with different layouts, and either print the final map or distribute it in electronic form. Changes in the survey data (due to closing loops etc.) can be automatically reflected by both the composite sketch and in the map symbology. Carto executable and (java) source is available free of charge from http://www.psc-cavers.org/carto.

HIGH-PRECISION SURVEYS WITH A BRUNTON COMPASS

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A Brunton compass must be tripod-mounted to meet its full potential. With care, readings can be interpolated to 0.1-0.2 degree with a magnifying glass. Sighting ease and precision can be improved by optical tricks, customized tripod mounts, sharpening the pivot, and sharpening the needle point with a shaped dab of lacquer. Older designs without magnetic damping have more precise needles. The compass must be calibrated to true north, preferably by sighting on Polaris and correcting for time and latitude. Correcting for needle eccentricity can reduce error considerably. With a transit, a compass course with at least 4 radiating lines is staked out, and a sinusoidal pattern of discrepancy in compass readings indicates the eccentricity. Without this correction, average closure errors are about 0.1% over multiple-station loops at least 500 m long. To level the ballfield, Brunton entries in NSS survey contests have omitted the eccentricity correction. This correction reduces closure errors to within 0.05%, as shown by numerous loops in cave and surface surveys. Tripod mounting minimizes deflections caused by metal parts in helmets, eyeglasses, etc., and steeply inclined shots can be made accurately. Alternate foresights and backsights are most convenient, but repeated readings are required to catch blunders. These methods are not suited to all conditions, but surprisingly difficult terrain can be negotiated. They are best suited for specialized purposes, such as geologic mapping or running base lines through major passages.

VISUALIZATION OF CAVE SURVEY DATA IN 3D USING ARCVIEW GIS

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ArcView® GIS is a popular desktop GIS used by cave and karst managers to store and manage cave survey and inventory data as well as perform GIS analysis. The ArcView® GIS 3D Analyst extension provides additional tools and capabilities that can be used to visualize cave survey data and other GIS layers in 3D. Several methods and techniques are available to incorporate cave survey data into the 3D Analyst, including surface drapes, direct 3D data conversion, incorporation of 3D DXF files, model construction using 3D panels, and other methods.

INDEX TO VOLUME 62 OF THE JOURNAL OF CAVE AND KARST STUDIES

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This index covers all articles and abstracts published in volume 62 parts 1, 2, and 3. Selected abstracts from the 1999 Society meeting in Filer, Idaho, and the 2000 Society meeting in Elkins, West Virginia, are included.

The index has three sections. The first is a **Keyword** index, containing general and specific terms from the title and body of an article. This includes cave names, geographic names, etc. Numerical keywords (such as 1814) are indexed according to alphabetic spelling (Eighteen fourteen). The second section is a **Biologic** names index. These terms are Latin names of organisms discussed in articles. For articles containing extensive lists of organisms indexing was conducted at least to the level of Order. The third section is an alphabetical **Author** index. Articles with multiple authors are indexed for each author, and each author's name was cited as given.

Citations include only the name of the author, followed by the page numbers. Within an index listing, such as "Bats", the earliest article is cited first.

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