2019 NATIONAL CAVE AND KARST MANAGEMENT SYMPOSIUM PROCEEDINGS

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NCKMS 2019

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A GOOD PLACE TO CAVE

PROCEEDINGS OF THE TWENTY-THIRD SYMPOSIUM

DCR
Virginia Department of Conservation & Recreation

7 – 11 October 2019
Bristol, Virginia

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NATIONAL CAVE AND KARST MANAGEMENT SYMPOSIUM 2019

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West Virginia Cave Conservancy: Ken Walsh, Bill Balfour

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FOREWORD

The 23rd National Cave and Karst Management Symposium (NCKMS) was held in Bristol, Virginia, in October 2019. About 100 people from various places and perspectives gathered, united by a shared interest in cave and karst science, management, and conservation.

Dr. Julian "Jerry" Lewis started things off by dedicating the 2019 Symposium to the legacy of Dr. John "Captain Karst" Holsinger, and Dr. Dave Culver's keynote presentation highlighted John's multifaceted approach to cave conservation. Wednesday's field trip covered much of Holsinger's stomping grounds from his early years as a professor at East Tennessee State University when he developed an intense interest in the caves and karst of "the Mountain Empire". Prior to the Symposium, the Appalachian Cave Conservancy, Cave Conservancy of the Virginias, the West Virginia Cave Conservancy, the Nature Conservancy, and the Virginia Department of Conservation and Recreation led wild trips into caves they manage, including several of John's favorites. The *All About Lirceus* field trip led by Jerry Lewis ended at the Cedars Natural Area Preserve, home to the Lee County Cave Isopod, a species receiving federal protection thanks to Holsinger.

One of the main topics of the 2019 NCKMS was management of cave and karst resources on private lands. Tuesday's focus was on the role played by cave conservancies in identifying and protecting exceptional caves and karst, as well as teaching people about them through outreach events and programs such as Project Underground, now managed by the Southeastern Cave Conservancy. Tuesday night we all gathered at Bristol Station Brewery to trade stories, see a bat flight, enjoy libations, and even play a little music. Wednesday we explored the karst of the Mountain Empire. At Natural Tunnel State Park, many for the first time saw a cave with a railroad through it. We toured Gap Cave at Cumberland Gap National Historic Park, where a partnership with the Cave Research Foundation allowed exploration to continue during the time of white-nose syndrome. The day ended at the Gray Fossil Site and Museum, East Tennessee State University, where thousands of fossils continue to be dug from a Pliocene Epoch karst feature. After dinner, Dr. Blaine Schubert regaled us with tales of ice age bears from the caves and cenotes of Mexico's Yucatan Peninsula. Thursday and Friday were devoted to the science and technology that support cave conservation. Extra entertainment at Thursday night's banquet came from a silent auction to raise money for the Symposium and Blase Lasala's virtual reality tours of the Timpanogos Cave System, as entertaining to watch others experience as to take yourself! Cave Conservancy of the Virginias Chairperson Mike Ficco concluded his banquet presentation with the announcement that the conservancy was acquiring Madison Saltpetre Cave, furthering the conservation legacy of Captain Karst.

A big thank you to the generous sponsors who helped make the 2019 NCKMS a success, and to the George N. Huppert Scholarship Program for making it possible for many students and other members of the caving community to attend NCKMS. See y'all in Texas in '21!

The 2019 National Cave and Karst Management Symposium Planning Committee

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JOHN HOLSINGER REMEMBERED: BIOLOGIST, CAVER, CONSERVATIONIST, SPELEOLOGIST

David C. Culver[1c], William D. Orndorff[2]

Dr. John Holsinger died on November 18, 2018, at the age of 84, after a remarkable and unparalleled career as a taxonomist of subterranean amphipods from all over the world. Moreover, he was a speleologist in the broadest sense of the term—exploring, mapping, and cataloging caves; documenting geologic settings and processes; investigating water flow paths using tracer dyes; describing new species and studying the biodiversity of cave life; and working to protect and conserve caves. It is this last role that is the focus of this paper.

John Holsinger was born and raised in the Shenandoah Valley surrounded by caves and karst. As an undergraduate student at Virginia Polytechnic Institute (VPI, now Virginia Tech) majoring in biology, John served in the Corps of Cadets and was on the Hokie Cheerleading Squad (Roble, 2019). In 1954, he discovered organized caving through the VPI Cave Club, a student grotto of the National Speleological Society (NSS), and caves quickly became his primary focus. In the late 1950s and early 1960s, with John E. Cooper (Fig. 1), he initiated a biological survey of Virginia caves supported by the NSS. This was one of the very first such undertakings anywhere in the world, and was important because it departed from the usual rather narrow taxonomic focus of cave biologists, and was to prove to be of great importance in cave conservation planning.

After a stint in the army and as a teacher, Holsinger completed a Master of Science degree at Madison College (now James Madison University or JMU) in Harrisonburg, Virginia. His 1963 M.S. thesis included a checklist of organisms found in Virginia caves. This was the first of three such checklists, the other two being monograph-length enumerations of the Virginia cave fauna: Holsinger and Culver (1988) and Holsinger et al. (2013). This inventory work places Virginia today in third place in terms of the number of cave-limited species after Tennessee and Texas. Holsinger obtained his Ph.D. in 1967 working under Thomas C. Barr at the University of Kentucky, performing a taxonomic revision of a large group of subterranean crustaceans, now placed in the amphipod genus *Stygobromus.* John continued this taxonomic work for more than 40 years, formally describing more than 100 species new to science, 40 of them from Virginia alone. For more on John's academic accomplishments, see Culver (2018) and Roble (2018).

Following completion of his doctorate, John spent 2 years as a biology professor at East Tennessee State University in the heart of the Appalachian karst, then joined the faculty of the Department of Biological Sciences at Old Dominion University in Norfolk, Virginia, where he spent the remainder of his career. Ironically, though Holsinger returned to his home state, he was far from the caves and karst he loved. The move necessitated regular road trips, many with fellow caver and wife Linda, during summers, holidays, and long weekends to the karstlands of the Shenandoah Valley, Alleghany Highlands, southwestern Virginia, and the Greenbrier Valley of West Virginia.

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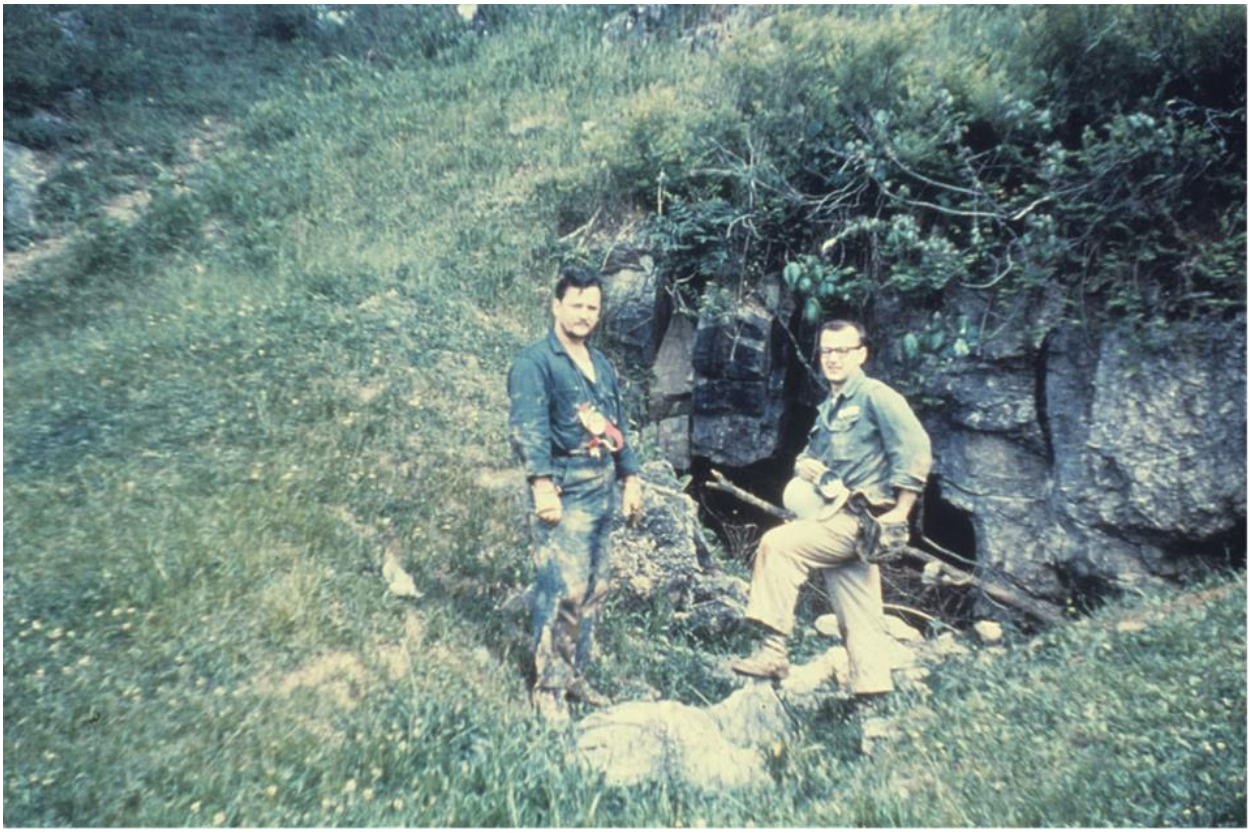

Figure 1. John Holsinger and John Cooper (left) at the entrance to Showalters Cave, Rockbridge County, Virginia, on a collecting trip in May 1961 that marked the beginning of the NSS-sponsored Biological Survey of Virginia Caves. The cave entrance was later collapsed by the owner, another example of the need for promoting awareness of and establishing protection for caves. (Photographer unknown)

During the same time period, John became an avid discoverer and reporter of caves, and was a significant contributor to *Caves of Virginia* (Douglas, 1964), published by the Virginia Cave Survey (VCS). Many of his cave discoveries were in the "Mountain Empire" of extreme southwestern Virginia, where in 1961 John helped establish the annual Thanksgiving weekend tradition of cave exploration known as DOM—Dirty Old Men—which would continue annually for over half a century. Henry Douglas handed over the reins of the VCS to John in 1964. In 1975 he published *Descriptions of Virginia Caves* (Holsinger, 1975), with maps and descriptions of hundreds of previously undescribed caves. John then handed the database of Virginia caves over to Phil Lucas and the newly formed Virginia Speleological Survey (VSS) (Collings, 2002). Over the course of his lifetime John would be the first reporter of over 400 of Virginia's caves. No other individual contributor to the state cave database comes close. John's dedication and leadership earned him the moniker "Captain Karst", a major deity in the pantheon of caving. Though John would continue to contribute to the VSS throughout his lifetime, his focus shifted toward conservation and biology.

Through his experiences exploring caves and their biology, John became increasingly aware of the critical need for cave and karst conservation. John's discovery of leakage into Banners Corner Cave of sewage from overlying houses in 1966 was one of Virginia's first documented

connections between overlying land use and the cave environment. Sinkholes used as trash dumps, broken formations, plundered artifacts, intentionally collapsed cave entrances, passage walls covered in graffiti, and caves completely destroyed by quarrying or construction provided regular reminders of the fragility of caves and their inhabitants. Something had to be done. Moving forward, there was hardly any cave conservation activity in the Virginias in which John was not a major player.

Although Virginia had first established legal protection for caves under the Cave Protection Act of 1966, its scope was narrow and enforcement difficult. In 1978, John Holsinger was part of a delegation from the Virginia Region of the NSS that met with state legislators and persuaded them to establish a commission to "study all problems incidental to cave use, protection, and conservation in Virginia" (Lera, 2009). John was the Virginia Cave Commission's vice-chairman under John Wilson, and with colleagues Evelyn Bradshaw, Robert Anderson, Roy Clark, Wayne Clark, Robert Custard, Henry T.N. Graves, John Kettlewell, Philip Lucas, and Virginia Tipton submitted their findings in 1978 to the governor and general assembly (Lera, 2009). They recommended drafting a new, more comprehensive Cave Protection Act that would protect cave resources while respecting private property rights. The result was the Virginia Cave Protection Act of 1979 (https://www.dcr.virginia.gov/natural-heritage/vcbprotact), which established permitting procedures for scientific research, specified penalties for vandalism, mandated the creation and maintenance of a list of significant caves, and made the Cave Commission a permanent, governor-appointed entity, renamed the Virginia Cave Board in 1985 (Lera, 2015). Holsinger led the development of the original list of 220 state designated Significant Caves, and served for 30 years on the Virginia Cave Board (1978–1996, 2000–2012), including as Chairperson in 1982 and from 1988 through 1994 (Roble, 2019). For more on the Virginia Cave Board, see Doctor, Lindeman, and Weberg (this volume.)

John also pursued conservation of and legal protection for cave-limited species through other venues. For example, as a member of the Arthropod/Invertebrate Taxa Committee of the Virginia Department of Game and Inland Fisheries, he advised the agency concerning species worthy of conservation attention and protection under the Virginia Endangered Species Act (Roble, 2019).

Holsinger was instrumental in the listing of two cave-adapted invertebrate species from Virginia under the U.S. Endangered Species Act—the Madison Cave Isopod (*Antrolana lira)* as threatened in 1982 and the Lee County Cave Isopod (*Lirceus usdagalun)* as endangered a decade later. Though both isopods, these two rare crustaceans come from radically different karst settings in different parts of the state.

The Madison Cave Isopod, which Holsinger, along with Tom Barr, discovered in 1958, is a cirolanid isopod found in parts of the Shenandoah Valley where the phreatic karst aquifer intersects cave passages and wells. It is the only Appalachian cave species whose closest relatives are marine. It was listed as threatened due to a proposed (now built) water tank in the hill above Madisons Saltpetre Cave, the only known site for the species at the time (Fig. 2). Subsequent inventory efforts for the isopod have shown its range to extend for about 150 miles from Lexington, Virginia, to Charles Town, West Virginia. The Madison Cave Amphipod (*Stygobromus stegerorum)* — discovered and described by John, of course — was listed as state endangered at around the same time, and turned out to be much rarer than the isopod.

Figure 2. John Holsinger examining biological samples in Madisons Saltpetre Cave, Augusta County, Virginia. (Photo by Dave Hubbard, 1992).

The Lee County Cave Isopod, by contrast, is an asellid isopod restricted to a handful of shallow cave streams and their resurgence springs in the Cedars area of central Lee County, Virginia, and was listed endangered due to its extirpation from Thompson Cedar Cave, one of two localities known at the time, caused by sawdust and associated leachate draining into sinkholes feeding the cave stream. Despite significant inventory efforts, the global range of *L. usdagalun* remains less than 10 miles.

John promoted the direct conservation of individual caves through a variety of means. He had long-term relationships with the owners of many of Virginia's most biologically significant caves. Access to many of them was only possible if Captain Karst vouched for you, and he wasn't averse to difficult conversations with landowners regarding how their land use might adversely affect the cave, or about the fate of the cave after the owner's lifetime. To this day, many cave owners encountered in western Virginia will inquire or reminisce about John when you knock on their door. In rare instances, John's principled stands resulted in a lack of access to some caves. For example, the listing of the Lee County Cave Isopod forced the relocation of a proposed federal prison to avoid affecting the species, angering the local board of supervisors and citizens who stood to benefit financially from the project.

John advocated for conservation ownership of caves, through both The Nature Conservancy and the Virginia Department of Conservation and Recreation's Natural Heritage Program (VNHP). He worked with Don Gowan at The Nature Conservancy to acquire Unthanks Cave in Lee County, the type locality of *Holsingeria unthanksensis* (Holsinger's Cave Snail). Long time

VNHP Natural Areas Manager Larry Smith was a botanist by training, but through the Cave Board John was able to convert him into a staunch advocate for cave and karst protection. The result of this partnership was the addition of numerous biologically significant caves across western Virginia to the State Natural Area Preserve system, including Ogdens Cave, Stay High Cave, and all six caves from which the Lee County Cave Isopod is known, as well as hundreds of acres that comprise The Cedars Natural Area Preserve (Fig. 3). These caves include Thompson Cedar Cave, which, through an interagency effort led by the Cave Board, slowly recovered from the sawdust contamination, with the isopod recolonizing the cave from a refugia in an upstream tributary. And Unthanks Cave is now owned by VNHP, which is slowly acquiring additional land in the cave's recharge zone.

Figure 3. John Holsinger in the early 2000s discussing the karst of the Cedars over Thompson Cedar Cave with Wil Orndorff and Chris Hobson of the Virginia Natural Heritage Program and Shane Hanlon of the U.S. Fish and Wildlife Service. (Photo by Dave Culver)

The influence of the Holsinger-led Cave Board prompted the VNHP to establish a small, permanent program (https://www.dcr.virginia.gov/natural-heritage/karsthome) with staff dedicated to the study and conservation of the biodiversity of Virginia's caves and karst. This conservation legacy continues to grow posthumously, as Madisons Saltpetre Cave was recently purchased by the Cave Conservancy of the Virginias in cooperation with VNHP and dedicated as a State Natural Area Preserve, the culmination of 60-year relationship with the family that owned the cave.

John Holsinger's contributions to the conservation of caves and their fauna extended across the United States and around the globe. He served as advisor to federal agencies including the Fish

and Wildlife Service, the Forest Service, the National Park Service, the National Marine Fisheries Service, and the Natural Resources Conservation Service. He provided guidance to state agencies across the United States, and worked across political boundaries with non-governmental conservation groups such as The Nature Conservancy and the World Wildlife Fund (Roble, 2019). He co-authored research papers with colleagues from across the world, including France, Russia, and Slovenia. He was a stalwart at the biannual meetings of the International Society for Subterranean Biology, delivering plenary lectures at meetings in Italy (2002) (Fig. 4) and India (2004) (Roble, 2019). John introduced visiting scientists from around the world to the Appalachian karst and was advisor to several international graduate students.

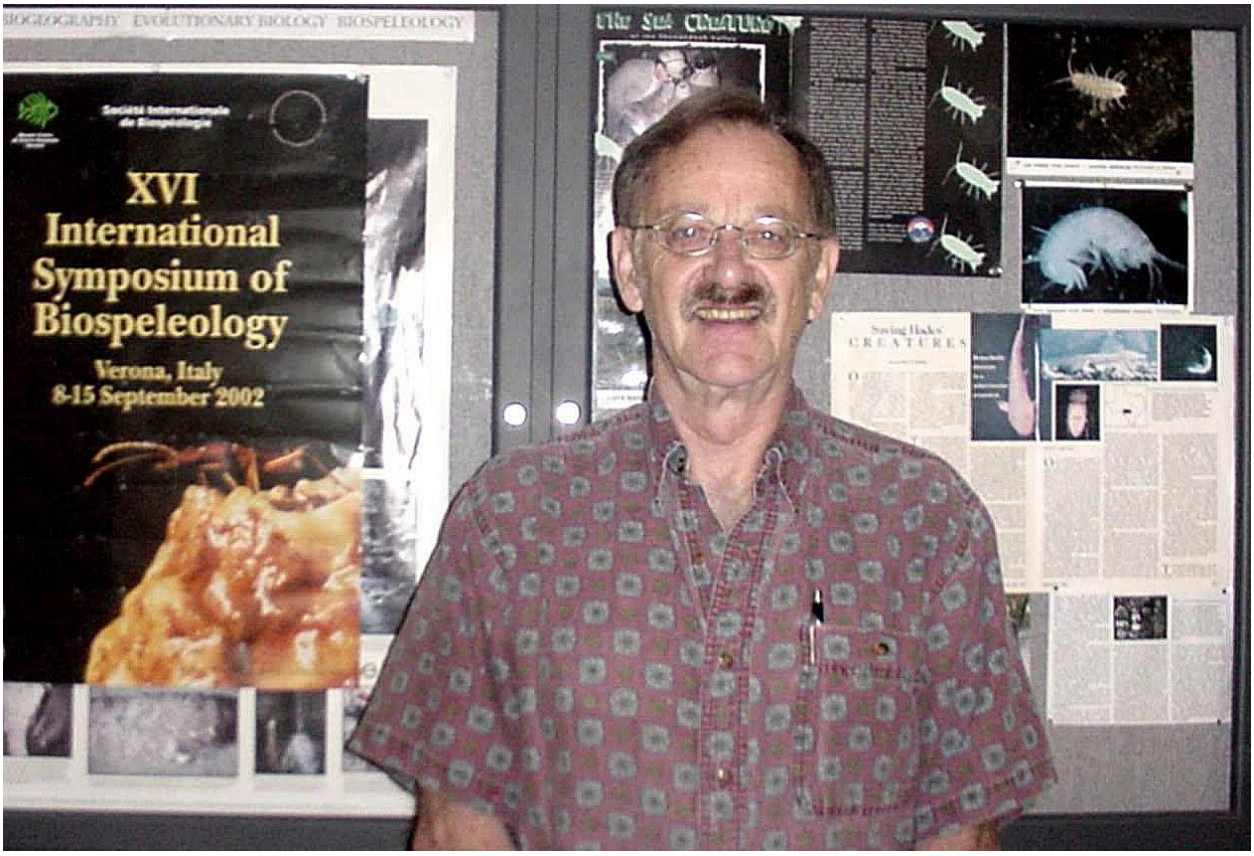

Figure 4. Holsinger at the 2002 meeting of the International Society for Subterranean Biology, showing off some of his favorite cave critters: (clockwise from corner) the Lee County Cave Isopod (*Lirceus usdagalun),* a cave amphipod (*Stygobromus sp.)*, and the Madison Cave Isopod (*Antrolana lira)*. (Photo by Dave Culver)

John Holsinger shared his conservation ethic and scientific rigor with former students like Julian "Jerry" Lewis, Lynn Ferguson, and Jill Yager, and professional and caving colleagues including Dan Fong, Chris Hobson, Dave Hubbard, Horton Hobbs III, Terri Brown, Bill Balfour, Bill Jones, Roger Baroody, Dan Feller, and the authors of this paper.

Perhaps the key to John Holsinger's success as a conservationist is the critical role both his biological inventory and cave descriptions played in providing objective information about caves and their significance. The early role of these lists was just to publicize the existence and importance of caves at a time when his was a lonely voice advocating cave protection. Today, these lists continue to be updated, expanded, and maintained by those following John

Holsinger's lead, and provide the basis for prioritizing cave and karst protection efforts. He was one of the very few speleologists equally comfortable in the exploration, biology, and conservation communities, and it can be argued that this interdisciplinary approach was his greatest asset.

But let's not forget about the Hokie Cheerleading Squad. John was always an enthusiastic cheerleader for the study and conservation of caves and karst, and had the ability to motivate people to act for the cause. Captain Karst would call the VNHP Karst Program at least monthly and sometimes weekly just to get updates on "what's going on in the Cedars," but his real agenda may have been to encourage staff and make sure they were doing a good job. Over 40 years, his cave biology course at ODU often included nontraditional students from agencies including VNHP, conservation organizations, and the caving community, and featured multi-day field trips to the Appalachian karst that gave John a bully pulpit from which he promoted the study and conservation of caves (Roble, 2018). Conservation is a huge job that requires the dedication and cooperation of many people from a variety of perspectives, and John led the way by example and with enthusiasm (Fig. 5.)

"Karst über alles!"

Figure 5. Captain Karst astride the speleocycle at the entrance to Smiths Milk Cave, Lee County, Virginia. The Cave Protection Act sign is one of the many conservation products of the Virginia Cave Board. (Photo by Wil Orndorff)

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APPALACHIAN CAVE CONSERVANCY (ACC)

Terri Brown[1c]

The Appalachian Cave Conservancy (ACC), Inc. is a non-profit organization formed in 1978 as the Perkins Cave Conservation and Management Society by long-time caver and cave conservationist, John Wilson. Our mission has always been to apply best management practices to the protection of caves on privately-owned lands in the Appalachian region. The organization's original focus was on the management of Washington County, Virginia's Perkins Cave and its surrounding acreage. In 2004, the Conservancy adopted its current name and expanded its scope to include additional caves within the upper Tennessee River watershed of southwestern Virginia and northeastern Tennessee, a recognized hotspot of biodiversity. The ACC owns the Gilley Cave property in Lee County, VA, and currently manages nine caves in its service area through agreements with ACC members and friends of the conservancy. The ACC accepts donations of cave entrances and karst lands, and enters into voluntary agreements with landowners to develop and implement effective management strategies based on site-specific characteristics, threats, and land use conditions. One disadvantage of this approach is dealing with new and sometimes hostile landowners when cave properties are sold. Most ACC caves are open to visitation by responsible cavers, with a select few restricted to scientific or conservation-related visitation only. With the support of more than 60 members, ongoing ACC activities involve cave surveying, graffiti and trash removal, education and outreach, management plan development, gate building and repair, and fund-raising.

Emily Graham cleaning graffiti (left; photo by Steve Bailey) and Jeannie Bailey at "the Hoops" (right; photo by Janet Manning) during a cleanup at Gilley Cave.

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THE VIRGINIA CAVE BOARD: A UNIQUE RESOURCE FOR KARST MANAGEMENT IN VIRGINIA

Meredith Weberg[1c], Steve Lindeman[2], Daniel H. Doctor[1]

Abstract

This presentation provides an overview of the Virginia Cave Board (VCB), a unique advisory body on cave and karst issues in Virginia. The VCB was established in 1979 to conserve and protect the state's caves and karst landscapes, and to advocate for the wise use of karst resources. All members are volunteers appointed by the governor. The VCB is an independent advisory body administered by the Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program. The VCB and the Natural Heritage Program's karst team work both together and independently to protect and to educate the public about Virginia's biologically rich and environmentally sensitive caves and karst. Although the VCB is non-regulatory in nature, it has nonetheless been influential in advising on development projects in karst regions by producing documents such as guidelines for Karst Assessment Standard Practice, Frequently Asked Questions (FAQs) About Natural Gas Transmission Pipelines Through Karst Terrains, and A Resident's Guide to Sinkholes. The VCB hosts Virginia Cave Week, which promotes an understanding of Virginia's caves and the surrounding karst. The VCB also established the Virginia Cave and Karst Trail, highlighting a number of publicly accessible sites across the state that enable citizens to learn more about Virginia's cave and karst ecosystems, and publishes the *Virginia Cave Owners' Newsletter* at least once per year. All the aforementioned documents are available online at the VCB website: https://www.dcr.virginia.gov/natural-heritage/cavehome

Background

The first Virginia Cave Protection Act (the Act) was enacted on March 2, 1966. In 1979, the Virginia General Assembly created the Virginia Cave Commission and strengthened the Act (Fig. 1). The main purposes of the Act were to protect cave resources from vandalism and degradation and to protect cave owners' interest in their property. Violations of the Act are Class 3 misdemeanors with fines up to $500. The Virginia Cave Commission was renamed the Virginia Cave Board in 1985.

Cave Board members are all volunteers appointed to 4-year terms by the Governor. New members are nominated by standing members of the Cave Board to represent a diverse set of skills and backgrounds, or they can nominate themselves. Some of the members are cavers; others, like current chairman, Dr. Dan Doctor, are professional geologists. Steve Lindeman, with The Nature Conservancy, works to acquire properties important for the conservation of biologically significant caves in southwest Virginia, like Unthanks Cave, Surgenor Cave, and Thompson Cedar Cave in Lee County, VA. Other fields of interest represented by the current Board include a show cave owner, a landowner who owns a couple caves, an attorney within state government, and a college professor of geology.

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VIRGINIA CAVE BOARD MANDATE

VCB was established by the 1979 General Assembly and may perform these functions:

- Serve as an advisory board to other state agencies on matters related to caves and karst,
- Keep an inventory of publicly owned caves,
- Provide cave management expertise and service to other state agencies as requested,
- Identify significant caves in Virginia,
- Report on ways to assist local authorities in obtaining the assistance of experienced cavers for cave rescues,
- Clarify laws relative to cave ownership,
- Suggest ways for enforcing the Cave Protection Act effectively,
- Study the possibility of a state cave recreation plan, and
- Study how cave data might be stored through electronic data processing so as to be readily available to state agencies with a need for such information.

Figure 1: A summary listing of the legislative mandate of the Virginia Cave Board.

Outreach

In its early years, the Cave Board did a lot of outreach, going to festivals and setting up displays. The Cave Board focused on providing advice to the public and other state entities about the importance of caves and karst. Over time, with renewed interest from new members, the Cave Board has refocused on outreach.

Virginia Cave Week is an important part of this outreach. The first Cave Week was in 2002 and it wasn't an annual event until more recently. Now, each year, the Cave Board comes up with a theme for educators to use in their classrooms. In 2019 we honored the memory of Dr. John Holsinger, a world-renowned scientist whose work focused on caves and their inhabitants, especially amphipods.

Throughout Cave Week, Cave Board members offer talks and walks along the Virginia Cave and Karst Trail, which is another major outreach project we've done. A few sites along the trail were included in the symposium field trip. Hopefully, those on the trip took a brochure and checked off those sites that were visited (Fig. 2).

Caves, karst and critters

Eight species of bat rely to varying degrees on caves in Virginia for hibernation, to raise their young and as a refuge from predators. In Virginia, nearly 200 invertebrate species live only in caves. Eyeless and frequently white or translucent, these species are adapted for life in the dark. Many inhabit just one or two caves. Within the freshwater-filled caves of the Shenandoah Valley lives the Madison Cave Isopod, a crustacean that evolved from a marine-dwelling ancestor to become adapted to living in Virginia's karst aquifers more than 20 million years ago. Fossils of Ice Age animals, such as mastodons and short-faced bears, can be found in Virginia's caves. The Museum of the Middle Appalachians in Saltville tells the story of ice age animals trapped in ancient sinkholes, and displays life-size replicas of these animals as well as the actual bones and fossils of mastodons, woolly mammoths, musk oxen, black bear, horses, small mammals, birds, and fish. New fossils continue to be discovered at this working museum, where karst features provide a key window into the understanding of Virginia's Natural History. Karst is a dynamic landscape, full of unique and fascinating natural history. We hope you will enjoy exploring it.

About the trail

The Virginia Cave and Karst Trail is a collaborative project between the governor-appointed Virginia Cave Board and the Virginia Department of Conservation and Recreation (DCR). DCR manages programs for cave and karst protection and education.

The Virginia Cave Board

Established by the Virginia Cave Protection Act, the Virginia Cave Board advises individuals, organizations and public agencies on cave- and karst-related matters; provides cave management expertise; prepares and presents educational material; identifies significant caves; and recommends conservation and preservation measures for cave resources within Virginia. Board members include an array of educators, geologists, biologists, engineers, professors, conservationists, cave owners and cavers appointed by the governor. Visit www.dcr.virginia.gov/natural-heritage/cavehome for more details.

This brochure was made possible by a generous donation from the owners of Luray Caverns and the Virginia Cave Board, Virginia Department of Conservation and Recreation. ©2019

Photos: Karst window, Irv Wilson; Madison cave isopod, Susan Middleton and David Littschwager, 1993; Big brown bat, Wil Orndorff, Luray Caverns

VIRGINIA Cave & Karst TRAIL

www.dcr.virginia.gov/natural-heritage/vacavetrail

A world beneath our feet

Caves figure prominently in Virginia's natural and geologic history. More than 4,400 have been documented here, and many harbor delicate natural communities with a diversity of species. Caves were mined for saltpeter during the Civil War, designated as bomb shelters during the Cold War, used as speakeasies during prohibition, developed as tourist attractions, and used to store food and supply water. Caves continue to be discovered, explored and studied by explorers. Scientists and conservationists in particular focus on caves and natural resources inside them.

Why is karst important?

Karst landscapes are characterized by sinkholes, sinking streams, springs and caves. Karst is found in areas where mildly acidic groundwater has dissolved soluble rock, such as limestone, dolostone, marble and gypsum. Virginia is rich in karst resources, and they play an important role in water quality and supply. Tens of thousands of Virginians depend on karst aquifers for clean drinking water but, because karst landscapes are porous, groundwater can easily be contaminated by surface runoff. Conservation of karst landscapes and education about their sensitivity to pollution are imperative.

Learn about geology

The geologic processes that produced Virginia's karst landscapes began more than 500 million years ago when a shallow tropical sea, abundant with life, covered much of the North American continent. Many organisms in the sea secreted hard shells and other protective body parts made of the calcium carbonate minerals calcite and aragonite. For much of the next 200 million years, their remains fell to the sea floor and mixed with other sediments to form layers, or strata, of the rocks limestone and dolomite more than 10,000 feet thick. Between 325 and 260 million years ago, the strata were uplifted and deformed by tectonic forces into the folded and faulted rock strata of the Appalachian Mountains. The Appalachians have been uplifted and eroded at least twice since then and continue to rise, producing the mountainous landscapes we see today.

The weathering processes that formed Virginia's present karst landscapes occurred over millions of years. Many karst features, such as sinkholes and caves, were destroyed by erosion as new ones formed, but occasionally evidence is found in the karstic "pockets" of the Earth of how long these landscape features have persisted.

The Virginia Cave and Karst Trail

The trail has more than 20 stops where visitors learn about and appreciate outstanding caves and karst features. The trail is meant to educate people about these sensitive environments and to promote their protection.

About a dozen caves in Virginia have been developed into show caves. These caves attract visitors from around the world, contribute to local economies and provide visitors amazing views of caves they wouldn't otherwise see. The Virginia Cave and Karst Trail features eight show caves.

Most stops are in Virginia's scenic Ridge and Valley province. Each offers visitors a unique experience such as an interpretive program, a scenic view or fee-based tour. A few stops have trails or self-guided tours.

With a bit of planning, several stops can be covered in a day. Be sure to contact commercial sites for information about admission fees and hours of operation.

How many Virginia Cave and Karst Trail sites can you visit?

- ☐ 1. Abrams Creek Wetland Preserve
- ☐ 2. Augusta Springs
- ☐ 3. Cowpasture River Trail
- ☐ 4. Dixie Caverns
- ☐ 5. Endless Caverns
- ☐ 6. Falling Spring Falls Overlook
- ☐ 7. Falls Ridge Preserve
- ☐ 8. Gap Cave
- ☐ 9. Grand Caverns
- ☐ 10. Hupp's Hill Civil War Park
- ☐ 11. Luray Caverns
- ☐ 12. Museum of the Middle Appalachians
- ☐ 13. Natural Bridge State Park
- ☐ 14. Natural Chimneys
- ☐ 15. Natural Tunnel State Park
- ☐ 16. New River Cave Nature Preserve
- ☐ 17. Pinnacle Natural Area Preserve
- ☐ 18. Rockland Park
- ☐ 19. Shawnee Springs Preserve
- ☐ 20. Shenandoah Caverns
- ☐ 21. Skyline Caverns
- ☐ 22. The Caverns at Natural Bridge
- ☐ 23. The Cedars Natural Area Preserve
- ☐ 24. Virginia Living Museum
- ☐ 25. Wildwood Park

Figure 2: The Virginia Cave and Karst Trail brochure produced by the Virginia Cave Board that highlights cave and karst sites of interest that are accessible to the general public.

Advising

Another major responsibility of the Cave Board is advising, whether it be other state agencies, developers, or cave owners. The Cave Board has been instrumental in posting Cave Protection signs in significant caves around Virginia (Fig. 3).

Figure 3: The cave protection sign posted at the entrances of significant caves in Virginia.

Not long after the discovery of White-Nose Syndrome in bats in the U.S., the Cave Board put out a statement on what we thought were the best practices at the time. We have a number of publications and white papers on our website, including one on best practices for cleaning lampenflora, the algae that grows near artificial lighting in show caves. The Cave Board published a booklet, *Living on Karst*, in 1997 that is still useful today.

Most recently, Cave Board members have written letters to the Federal Energy Regulatory Commission (FERC) about the two proposed natural gas pipelines in the commonwealth. As a result, a number of significant caves and karst areas will be protected. We have also been involved in advocacy at the level of our state legislature to help craft legislation to strengthen cave and karst protection in Virginia. This is still a work in progress. In addition, we have written letters of support to organizations seeking funding for karst protection. A set of answers to frequently asked questions about natural gas pipelines routed through karst areas is on the Virginia Cave Board website (https://www.dcr.virginia.gov/natural-heritage/document/faq-nat-gas-trans-pipelines-karst.pdf).

The Virginia Cave Board is unique in the nation for the role its members play in striving to protect cave and karst resources. We have advised cavers in Tennessee and Indiana about forming similar groups. For more information about the history of the formation of the Virginia Cave Board, please see the publication “The Virginia Cave Board: The First Fifty Years (1966-2015)” authored by past Cave Board Chairman Thomas Lera (https://www.dcr.virginia.gov/natural-heritage/document/the-virginia-cave-protection-act.pdf).

CONSERVATION ASSESSMENT OF CAVE RELATED NATURAL HERITAGE RESOURCES IN VIRGINIA: PHASE 1, NEW RIVER KARST REGION

Thomas E. Malabad[1c], Katarina Kosič Ficco[1], William D. Orndorff[1]

The Virginia Department of Conservation and Recreation Natural Heritage Program (DCR-DNH) manages an inventory of rare, threatened, and endangered plant and animal species; exemplary natural communities; and biodiversity-associated geologic features. Locations of these Natural Heritage resources are known as Element Occurrences (EOs). EOs include caves designated as Significant under the Virginia Cave Protection Act of 1979. The Virginia Speleological Survey (VSS) maintains the list of Significant Caves on behalf of the Virginia Cave Board, an advisory body established by the Cave Protection Act. As of spring 2018, DCR-DNH tracked approximately 370 Significant Caves and an additional 500 EOs of cave-associated fauna, mostly obligate subterranean invertebrate species.

DCR-DNH designates Conservation Sites as geographic areas where activities might be expected to affect one or more Element Occurrence. Conservation Sites have no independent legal standing, but rather are used by DCR-DNH as a critical screening tool for reviewing development and other projects for potential environmental impacts, and for prioritizing conservation efforts. Sites are assigned biodiversity significance rankings (B-ranks) based on the number, rarity, and viability of EOs. DCR-DNH screens over 300 projects annually for potential impacts to caves and karst, mostly due to proximity to Conservation Sites. As a result, impacts to many caves have been avoided or mitigated. Examples include the relocation of projects away from significant caves, enhancement of storm water management and erosion and sediment control measures, modification of construction methods, monitoring of species and habitat, and in one case the cancellation of a project and establishment of a state Natural Area Preserve, Ogdens Cave Preserve in Frederick County.

DCR-DNH developed many of the cave-related Conservation Sites in the early 2000s based largely on desktop review using cave maps, geologic and topographic maps, and dye traces. However, as of 2017, a third of Virginia's Significant Caves had no biological records and thus were assigned low B-ranks, making them a low priority for protection and conservation efforts. Biological data on many other caves was incomplete or considered historic (over 30 years old) under Natural Heritage Program methodology and not considered eligible for consideration during assignment of B-ranks. Starting in 2018 with generous support from the Cave Conservancy of the Virginias, DCR-DNH began a multi-year effort to update cave-related Conservation Sites state-wide, starting in the New River Karst Region of Virginia—Bland, Craig, Giles, Montgomery, Pulaski, Roanoke, Tazewell, and Wythe Counties (Fig. 1). Table 1 shows the distribution of Significant Caves and other cave-associated EOs across Virginia's five karst regions. We aim to improve the documentation of Conservation Sites through new and updated biological inventory; assessment of habitat quality and threats; and verification of cave locations, ownership, and conservation status.

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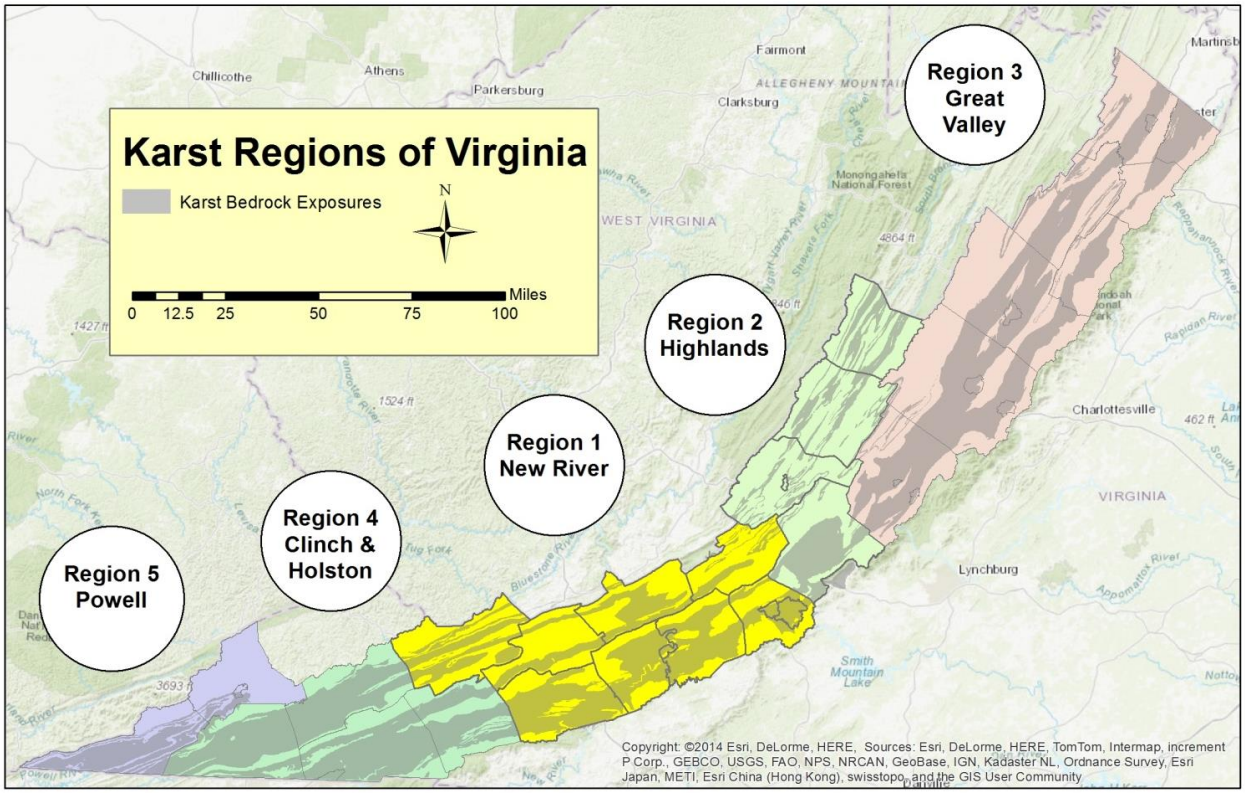

Figure 1. Karst Regions of Virginia as designated for conservation data update project.

Table 1. Cave-associated Natural Heritage Resources in Virginia (Spring 2018).

Natural Heritage Cave Resources	Karst Region New River (1)	Highlands (2)	Great Valley (3)	Clinch and Holston (4)	Powell (5)
Significant Caves	82	71	57	90	70
Other Element Occurrences	121	93	81	73	121

The verification of cave locations was one of the first steps necessary to update the cave Conservation Sites. To this end, DCR-DNH has been collecting GPS locations for caves that are visited during this project. Entrance locations that vary from the reported location within the VSS database are then submitted to the VSS to update the survey's records. In some cases, cave entrance locations were off significantly, as much as a quarter mile. Updates like this are crucial in order to be able to better define land areas overlying caves (aka cave footprints) and then delineate accurate Conservation Sites.

After entrance locations were verified, the existing cave conservation sites were reviewed and modified as needed. To accomplish this, maps of the caves were acquired from the VSS and

other sources. Most digital maps were in a PDF or JPEG format. As a result, we used the photo editing software GIMP to crop and edit them so that they could be imported and geo-referenced into ArcGIS. The ArcMap geo-referencing tool was used to place cave maps in correct locations based on the accurate entrance coordinates. Next, cave footprints were created by drawing polygons encompassing the land surface overlying the extent of known cave passages. In general, the new cave footprints are smaller and more accurate. Existing Conservation Site boundaries were evaluated and modified as necessary based upon cave footprints, geology, topography, and hydrology, including dye tracing data if available. Note that DCR-DNH shares the Conservation Sites, not the cave footprints, for conservation planning purposes. More detailed information is available on a site-specific basis and requires approval of the VSS if cave entrance locations are involved.

An example of the Conservation Site revision process is shown in Figure 2. Once the location of New Castle Murder Hole was updated, the cave map plotted, and the footprint polygon delineated, we recognized that the boundaries of the old cave footprint and Conservation Site were incorrect (Fig. 2). The respective boundaries were modified so that the cave now completely falls within the Conservation Site, which includes a second significant cave. The conservation site delineation is based in part on dye tracing performed by von Till (1993) and funded by the Cave Conservancy of the Virginias.

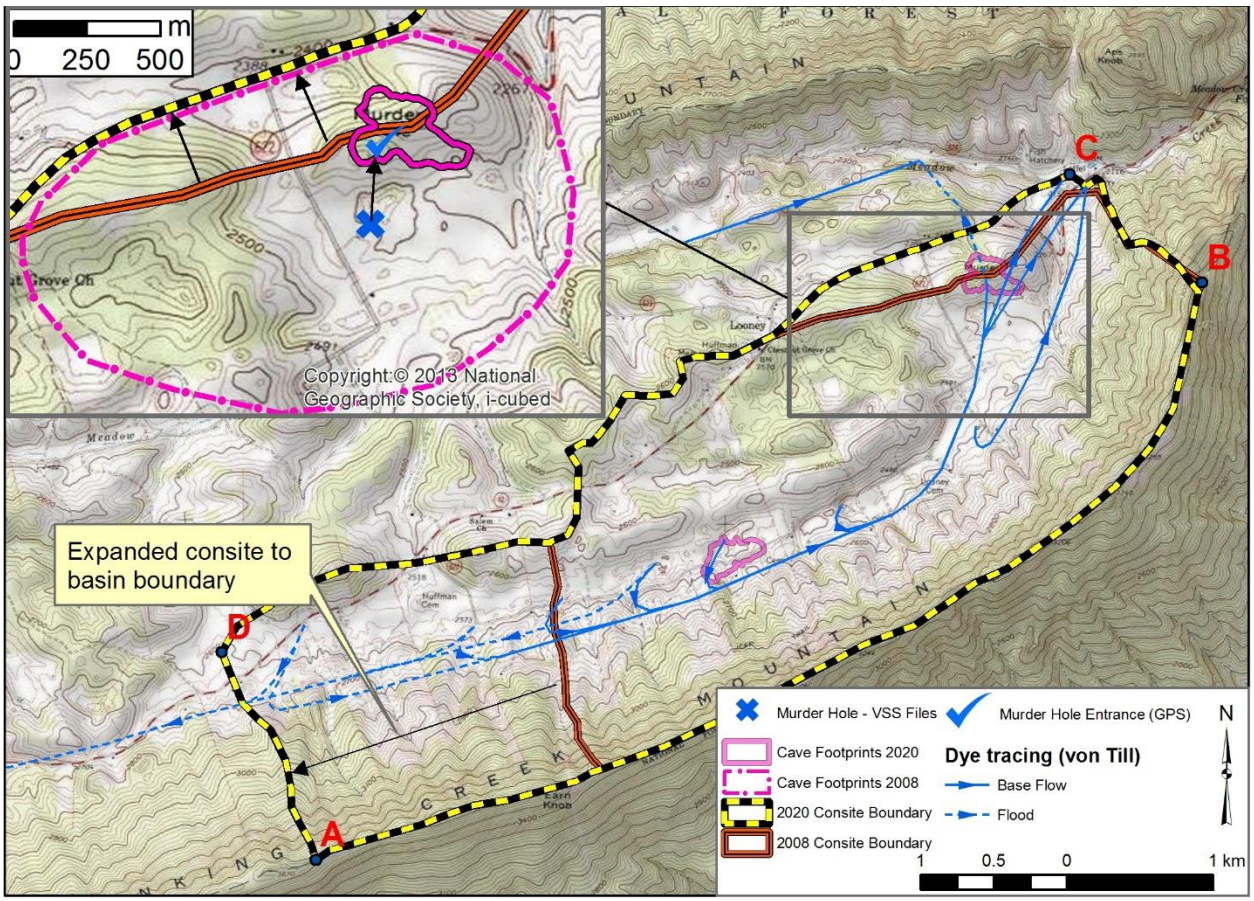

Figure 2. Example of updates to a conservation site based on cave location and hydrological data, Rufe Murder Conservation Site.

Points along conservation site boundaries are assigned control points in order to document the rationale for and confidence in specific segments, which is ranked 1 to 5 from low to high confidence. In Figure 2, the segment from control points A to B represents the top boundary of the allogenic recharge zone (land area underlain by non-karstic bedrock upslope from and draining to karst) in the watershed of the EOs. Segment A to B is assigned a confidence value of 5. B to C represents the lateral ridge spur from the allogenic boundary to the resurgence springs, and is also assigned a 5. C to D is the surface topographic divide marking the northwestern limit of surface drainage to sinkholes believed associated with the hydrological system to which the site belongs. The certainty assigned here is 3, because without extensive further dye tracing, the hydrological identity of specific sinks remains unknown. Finally, D to A is the lateral ridge defining the surface watershed of the westernmost sinkhole traced to the resurgence for caves in the conservation site and is assigned a confidence level of 4, since there may be untraced sinkholes farther west that are part of the system. Our overall confidence in the boundary for this site is high, estimated at 4 out of 5.

In some instances, sites were completely redefined or even eliminated. New Conservation Sites were drawn for caves associated with natural heritage resources, including some Significant Caves, which did not fall within existing sites. The revised Conservation Sites greatly enhance the ability of DCR-DNH to focus conservation efforts on critical areas during the project review process, ultimately helping to better protect sensitive karst resources.

Biological inventory of the Significant Caves within the New River Karst Region was the other major component of this project. At the start of the project, 82 caves in the New River Karst Region were listed as Significant and incorporated into 60 existing Cave Conservation Sites. However, biological inventories had never been performed in a quarter of these caves. Others had incomplete data or data based on collections over 30 years old (historic). Rare cave-adapted invertebrates were known from another 15 caves falling within an additional seven Conservation Sites. For 12 of the Significant Caves, we were either denied access or unsuccessful in attempts to contact landowners. Two caves have year-long bat closures and may be accessible under special agreement in the future. Quarrying operations have destroyed Erhart Cave, and landowners have buried the entrances of two additional Significant Caves.

We performed biological inventories in 63 of the 82 Significant Caves, including 14 of the 23 with no prior inventories. We did not visit two additional sites where we had recently performed thorough inventories, bringing the total number of significant caves in the project area with up-to-date biological inventories to 65 (80%.) Eight of the 15 additional caves with prior records of rare cave fauna were visited, as were nine additional caves falling within or proximal to existing Conservation Sites, bringing the total number of caves visited during the project to 80. As of March 18, 2020, species determinations by our taxonomist colleagues performed on collections from this project documented at least 130 new or updated occurrences of globally rare cave-limited invertebrate species. Numerous additional occurrences of rare species are likely to be identified as more determinations trickle in. Furthermore, taxonomists discovered multiple species new to science in project collections. New cave-limited species they are working to describe include an aquatic isopod from Lawson Cave in Tazewell County, an aquatic snail from the Sugar Run area of Giles County, a millipede found at three caves in Giles County, and new spiders from multiple locations. New species of pseudoscorpions, spiders, amphipods, diplurans, harvestmen, and beetles have also been tentatively recognized. The discovery of new species, additional records for rare species, and updates to old records have

allowed us to better assess the relative conservation value of Virginia's caves, as reflected in the assignment of more accurate and higher biodiversity significance ranks (B-ranks) to their respective Conservation Sites.

In summary, all cave Conservation Sites in the New River Karst Region were reviewed for accuracy and updated to reflect the current knowledge of the site based on existing and new biological inventory, geology, topography, hydrological data including dye tracing where available, and site-specific criteria such as historic and archaeological resources. Work on part two of the state-wide project to update cave-related natural heritage data began in late 2019 in the Highlands karst region of Virginia.

Conservation Sites are a dynamic tool for cave conservation. Biodiversity significance ranks will continue to be updated as species determinations come back from our taxonomist partners and as new collections and observations are made. Boundaries will be adjusted as additional hydrological studies are performed and as new cave passage is discovered. Maintaining up-to-date cave Conservation Sites is essential for screening threats to the cave and karst resources of Virginia and for prioritizing conservation efforts to protect them in the long term.

Acknowledgements
This work was made possible by a grant from the Cave Conservancy of the Virginias. Thanks to all taxonomists who performed species determinations from collections, including Robert Dillon Jr., Lynn Ferguson, Curt Harden, Chris Hobson, Kal Ivanov, Julian Lewis, Marc Milne, Karen Ober, Brandon Rhim, William Shear, and Charles Stephen. Finally, we would like to express appreciation to the owners of the caves for allowing us access for sampling and exploration and for their continued thoughtful stewardship of cave and karst resources.

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FILLING THE VOIDS – CAVE CONSERVANCY OF THE VIRGINIAS AND THE CAVE CONSERVANCY FOUNDATION

Mike Ficco[1c]

There is no shortage of potential projects in the world of cave and karst management and conservation. Many of us have lists of great projects that we'd like to see happen if only we had the resources and/or institutional flexibility to pull them off.

For nearly 40 years, the Cave Conservancy of the Virginias (CCV) and the Cave Conservancy Foundation (CCF) have been helping to bridge the voids between the ideas and the execution of those ideas. These two 501(c)(3) organizations accomplish this goal through a combination of grant awards for research and conservation, scholarships, public-private partnerships, and direct purchase/protection/management of properties.

CCV owns and manages two significant cave preserves* in Virginia, including the state's longest and deepest cave (the Omega Cave System). CCV is negotiating to purchase property that would establish its third significant cave preserve, funded by a grant from the US Fish and Wildlife Service as part of a Natural Resource Damage Assessment (NRDA) settlement pursuant to a nearby industrial site. CCV has also been instrumental in the purchase and protection of many other important cave properties in the Virginias by providing funding, purchasing rights of first refusal, funding biological surveys and hydrological studies, et cetera.

CCF's undergraduate and graduate scholarship programs have assisted dozens of students, helping them become leaders in the field of karst science, some of whom are likely in attendance at the 2019 National Cave and Karst Management Symposium (NCKMS.)

Moving forward, CCV and CCF endeavor to continue filling their historical roles in the cave and karst conservation communities, while pursuing collaborations and partnerships with other like-minded organizations as a way of adapting to the evolving environment of increased competition for seemingly decreased public funding of science and conservation.

To learn more about CCV visit https://caveconservancyofvirginia.org/.

For more information on CCF, go to http://www.caveconservancyfoundation.org/.

** - in March, 2020 CCV officially established its third preserve – The Madison Cave Hill Preserve – which protects two state designated significant caves and the overlying karst landscape.*

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THE NORTHEASTERN CAVE CONSERVANCY, INC. AN INTRODUCTION

Robert Simmons[1c], William Folsom[1]

The Northeastern Cave Conservancy, Inc. (NCC) was founded in 1978 to receive Knox Cave, a former commercial cave in upstate New York from the owner Dr. Delisa, who wished to see the cave preserved, but no longer wanted to retain ownership for liability purposes. In 1975, a large icefall off the side of the entrance sinkhole resulted in one fatality and one crippling injury to two college students that were entering the cave. The NCC was established with a small Board and managed this single cave property. In 1999, the NCC expanded its purview to become a membership based multi-preserve entity, operating at a 501 (c) (3) land trust with a nine-member board of directors and four officers running the day-to-day business of the conservancy. Since 1999, the NCC has added an additional eight preserves (with two more on the way) containing 15 known caves throughout east-central New York State. The NCC is seeking properties in the other states within its mandate (New England and New Jersey) and provides outreach, education, and assistance to groups, land owners, regulatory agencies, and other land trusts throughout the northeastern US. This talk will review the history of the NCC - its preserves, outreach efforts, and milestones in our growth - and take a candid look at issues (and answers) we have encountered along our way.

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RISK MANAGEMENT STRATEGIES FOR CAVE CONSERVANCIES

Mitchell Berger[1c]

Cave conservancies strive to grow – we want to protect more caves and karst, we want more volunteers and larger membership bases, and we want more of the public and the caving community to experience the wonders of nature that we dedicate our efforts to protect and preserve. With this growth comes an ever-increasing risk of something going wrong, and the risks we face are numerous and diverse. They include visitors or volunteers getting hurt on (or under) our land, vandalism, land deals that lead to disputed boundaries, unfriendly neighbors who cause damage to our land and danger to our visitors, accusations of discriminatory practices or mismanagement of funds, theft, and many others. We will explore several of these risks and a variety of options for protecting against them, along with the pros and cons of each option. Topics discussed will include waivers, conservation easements, various types of insurance (general liability, directors and officers, property, etc.), Terrafirma, “sportsman's laws,” etc. This presentation will show that risk management is not a one-size-fits-all affair, with the “right” mix of protections often depending on the size of your organization, available resources, and the jurisdictions in which you conserve caves and karst. A number of suggestions and resources will be offered to help devise a strategy that meets the needs of your cave conservancy, drawing heavily on the Northeastern Cave Conservancy's research and experiences over the last several years.

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USE OF CLARKSVILLE CAVE PRESERVE

Thom Engel[1c]

Clarksville Cave is owned by the Northeastern Cave Conservancy (NCC). A popular beginners' cave, it draws visitors from as far west as Buffalo to as far east as Boston, from Québec City to the north to Philadelphia to the south. From April 2012 to April 2014, data were gathered on the nature of the groups visiting the cave. Information gathered included group size and type, and how they were equipped. Additionally, individuals were asked about their affiliations with the NCC and the National Speleological Society (NSS), their knowledge of white-nose syndrome (WNS), and whether the trip was their first wild cave trip. There were many surprising results. The first was that over 20% of preserve visitors only visited the surface. The second unexpected result was that while over half of visitors had heard of WNS, they didn't understand that the goal of decontamination was to stop the spread of WNS from an affected cave to other sites. However, some did say that they understood spores from muddy clothing and equipment could contaminate their vehicles. The third surprise had to do with the affiliation of visitors with caving organizations. Only 8% of visitors belonged to the NCC and less than 12% belonged to the NSS.

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THE MID-ATLANTIC KARST CONSERVANCY

Jeff Jahn[1c]

In 1997, eleven cavers each contributed $10 to establish the Mid-Atlantic Karst Conservancy (MAKC) as a non-profit corporation in western Pennsylvania. MAKC's mission is the study, conservation, and preservation of caves and karst resources, and education of the public about those resources. MAKC now owns three preserves, leases six, and collaborates with other individual owners and public agencies to manage over 5,000 acres of karstlands including over 40 caves. In 2009 MAKC established the Bob and Bev Danielson Library and Education Center in Blairsville, PA in honor of its benefactors, creating a key focal point for karst education housing an extensive collection of domestic and international caving books and periodicals donated by cavers, including Jack Speece, the late Dale Ibberson, the late Jack Stellmack, and the York Grotto. 2019 was a banner year for MAKC, which used grants and donations to establish the Barbara Schomer Preserve, in honor of a long-time supporter of MAKC and Pittsburgh Grotto, to protect Sarah Furnace cave, a Van Port limestone cave with potential to be the longest in PA. MAKC also leased West Virginia's Silers Cave, a favorite among cavers from the Philadelphia, Baltimore, and DC areas, that had been closed for over a decade, then recently purchased by a caver willing to allow MAKC to manage access. A new survey is underway. Finally, MAKC is helping to manage Rupert cave in central PA, which has a pristine section limited to a few guided trips annually. The owners reached an arrangement with MAKC to lead trips when they are unable to do so. MAKC's strong membership is well positioned to meet challenges that include raising adequate funds and continuing to purchase or negotiate access to caves.

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THE WEST VIRGINIA CAVE CONSERVANCY: A BRIEF HISTORY

Bill Balfour[1c], Carroll Bassett[1], Cliff Lindsay[1]

The West Virginia Cave Conservancy (WVCC), a 501 c-3 non-profit organization, was founded in 1997. Its mission is to acquire and protect West Virginia caves and provide recreational opportunities where appropriate. Initially, the thought was to work primarily in the Greenbrier Valley, but the directors soon recognized the need to encompass the entire state and surrounding areas if we wanted to garner broad support among eastern cavers. The WVCC is composed of nine directors elected by the membership for a term of nine years, with elections staggered so that three directors are elected every three years. The elected directors appoint the officers of the corporation. WVCC holds three meetings per year, all open to all members, and hosts a banquet each fall in appreciation of the membership's support. The WVCC has been able to acquire access/ownership of three of the seven classic contact caves in the Greenbrier Valley giving cavers over 50 miles of cave to explore. Recent discoveries suggest that the largest cave system in the state may soon be realized with WVCC managing two of its entrances. The WVCC also owns the main entrance to another very popular 20 mile long system. In addition, the Conservancy owns two very popular recreational caves elsewhere in the state and two in Virginia, and has management agreements with two other properties in Greenbrier County. WVCC is currently pursuing acquisition of a cave in Tucker County.

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IMPLEMENTING AN ENDURING PUBLIC-PRIVATE PARTNERSHIP: THE CAVE RESEARCH FOUNDATION AND CUMBERLAND GAP NATIONAL HISTORICAL PARK

Bob Alderson[1c], Jenny Beeler[2], Terri Brown[3]

The partnership between the Cave Research Foundation (CRF) and the Cumberland Gap National Historical Park (CUGA) began in 2003. A Memorandum of Understanding (MOU) between CRF and CUGA provided guidelines for the Gap Cave Cartography Research Project and addressed National Park Service concerns about data sharing, security, and procedures. CUGA harbors an array of caves and karst resources and is the source of essential habitat and public drinking water supplies. The partnership between CUGA and CRF has resulted in the documentation of over seventeen miles of passage in Gap Cave alone, and the discovery of multiple virgin sections. These new discoveries, in turn, led to the development of specific conservation protocols intended to protect pristine areas. Prior to White Nose Syndrome (WNS), CUGA enforced policies designed to protect endangered species (such as Indiana bats) that included closing specified areas and caves during hibernation and access-control with bat-friendly cave gates. Beyond the developed tourist route, caver access was restricted to research, including survey, historical-cultural documentation, and hydrological and biological inventory. WNS arrived in the Virginias in 2009, and within a few years, populations of several bat species were decimated. Due to the potential for fungal spore transport on caving gear, further public-private cooperation between natural resource managers and the caving community led to development of decontamination procedures and varying caving restrictions. The US Forest Service closed all caves on its lands during this time, and other Parks required dedicated caving gear. CUGA, however, wrote a successful challenge cost-share proposal accounting for CRF's contributions that funded purchase of CUGA-dedicated caving gear plus equipment for washing and decontamination, and allowed CRF's research to continue. WNS was not documented in CUGA until 2013, despite the protocols, which may have delayed its arrival. As CRF expanded its research focus to include the preservation and documentation of Civil War signatures and investigation of seasonal hydrobiochemical signatures, CRF encountered some Wilderness designation restrictions that have been resolved through the partner interaction and permitting process. Any actions in Wilderness areas must go through a "minimum requirements analysis" step that adds extra time to a given project, but ultimately ensures that all options have been discussed and that the least disruptive practices will be employed. Due to our mutual trust factor and positive track record, CUGA (in consultation with the US Fish and Wildlife Service) has recently been able to advance from wholesale cave closure to protection of hibernacula during the winter months, to the point of allowing a limited number of winter scientific cave trips, as long as certain areas can be avoided. CRF's ongoing relationship with CUGA has been long and rewarding, and while there will always be challenges to deal with, we have seen caver feedback and communications incorporated into CUGA's management strategies in significant ways. What could possibly provide more validation than that?

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THE KENTUCKY KARST CONSERVANCY: HOW A CAVE GOT PROTECTED OVER DINNER

Kenneth Bailey[1c]

So, you want to save a cave. Is such a thing possible?

It all started at supper with James Patrick (JPat) Stevens before grotto meetings. JPat owned Kentucky's Big Bat Cave, and he and I would talk about its future while we ate. After about 6 months of these conversations I suggested figuring out how to keep caver access that would last in perpetuity. At the time, JPat's estate plan had the cave willed to his children. I said I would get a caving organization to buy the cave and that would settle the cave's future protection. That plan went nowhere; no local cavers or organizations wanted to buy the cave, and I did not know of any outside my area.

The next plan was to just buy the cave myself. It was a pretty good plan and maybe one I regret not doing. It might have been easier. After finding cavers willing to support the idea of building a nonprofit to own the cave, that became the plan instead. The idea that Big Bat Cave would be open to cavers forever was one that JPat was more than willing to get behind and he agreed to sell it to the newly formed Kentucky Karst Conservancy (KKC) and provide the financing himself. None of these ideas were in my original plan, they just kind of happened one day at a time.

I am a geographer who has become a snake oil salesman. I have now found myself president of a one-cave nature conservancy. I am now walk into rooms and try to convince people that they need to save a piece of wilderness that they get queasy just thinking about going into. I do my best to persuade them it is a good thing to do. The donations never equal the time I put into it. I think I could flip burgers and donate my paycheck and come out ahead. I want the hope that I may find someone who gets it and they direct their energy into putting Big Bat Cave back for future generations of cavers and non-cavers.

With the right accountant, getting a nonprofit started is pretty easy. However, getting the government to move the paperwork through the system when there is a scandal over the IRS removing political nonprofits is problematic, to say it nicely. I came up with the business model of selling keys to the gate for $250. You also get a lifetime membership to the KKC with that key. Key holders can take whomever they want into the cave whenever they want. There are two other categories of membership, annual with $15 yearly membership dues and a student membership at $8 per year. Key holding members may lend their key to any of the other two types of members. I have had college students pull up in my driveway and chip in the $8 to get one of them a membership and then leave with my key. I hope the stories they tell later on in life about their early college caving includes those trips and my key.

We paid the mortgage with key sales for a while. Then one year at the Tennessee Alabama Georgia (TAG) Fall Cave-In Ron Adams suggested we apply for a Central Indiana Grotto (CIG) grant. CIG gave us $600 and that is where the price for an institutional membership came from. CIG has a key and any member of CIG can join the KKC for free and be eligible to use the key

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and take whomever they want into the cave. Remember, this structure is not the result of a detailed plan, but rather just how things evolved over time.

The KKC paid the mortgage ahead and used the breathing room to write a grant request to support a vertical techniques training program. The Dogwood City Grotto gave us the seed money to buy loner gear. Darrian Dopp and the great people at Inner Mountain Outfitters (Jeff and Nina Martin) helped with the curriculum and the gear. The program lasts 2 days and costs participants $25. You don't need to be a KKC member to participate but it does get you to the front of the line. We make one or two mortgage payments annually from the income, plus we get to practice vertical techniques with some pretty neat people.

Ben Shinabery with QK4 Engineering in Louisville, Kentucky, bought a lidar data collector for the company's survey department. Ben was ahead of the curve on lidar and no one was using his services. I said I have a use for it. We took the scanner into Big Bat and started scanning. Ben and others honed their skills with lidar while we obtained some amazing images of the passages in Big Bat Cave. The goal of the Big Bat Cave Lidar Project was to get students who were busy earning rent money a line on their resume in one day instead of requiring a semester-long unpaid internship. Ben and I gave a talk on the project at a conference. It was standing room only and now Ben has so much work that we never get time to take his lidar machine underground. Ben has hired students out of the project. It was a win for us all.

Having Ben get way too busy meant we were going to have to rent a lidar machine. The plan became the 48-hour Big Bat Cave Lidar Project. We would rent the machine and run it around the clock. Precision Products in Louisville, specifically Kevin Kaufman and Eric Muncy, listened to my idea and let me try it. Some of it worked and other parts did not. We tried not to speak of the unpleasant parts and we eventually were able to rent there again. Let's just say we were all new to this.

Terri Brown with the Cave Conservancy Foundation (CCF) was our biggest champion on the first project. They helped fund a second 48-hour Big Bat Cave Lidar Project the following year. The CCF grants are to get projects started and they were successful with us. The project has gone on for 4 years now and we are fully funded for 2020. We have received grants from the Dogwood City Grotto (thank you everyone who goes to TAG) and the Cleveland Science Fund. Their support has meant the world to me and the project.

We currently have over 3 miles of passage scanned into lidar data. At the end of every exhausting 40- to 60-hour project I am inspired by the young cavers who show up and make this thing happen. The old cavers are nice to have around also. Anyone who volunteers has access to the data for noncommercial projects. We are open to commercial projects, so if you are thinking of something let us know. The data set has been used in a few master's degree projects on virtual reality and video just to get you thinking.

White Nose Syndrome (WNS) had an impact on Big Bat Cave, with a pre-WNS hibernating population of just under 1,000 bats. At least four different species including the endangered Indiana bat hibernated there. We now have a bat population of 40 healthy bats with two species staggering toward the extirpation line (a nice way of saying presumed extinct in the state). As a geologist, I have studied a few extinctions but they are fossils, sea creatures long turned to stone. Most of geology is static. I have seen mud slides and I hope to one day see an erupting volcano, but I never thought I would witness an extinction. The bats are not leaving a bone bed

so there will be very little evidence that they were even here and no fossil record of the extirpation event in Big Bat Cave.

There are other things that happen in Big Bat Cave and some of them could be their own paper, but 1,000 words of my rambling is enough for anyone. There will always be the day-to-day problems: where to get more money for the mortgage, getting the new owner of our right of way used to us, keeping the old neighbors happy, et cetera. It just never stops. Is it worth doing? For some probably not, for me I could not imagine doing anything else. All of us share ancestors that broke rocks in caves during the Stone Age. Caves gave us the protection we needed as a species until we could come up with our own, inferior structures. We owe a debt to caves. It is our turn to offer protection to pay off that debt. Caves are in our DNA. They are places that shaped humanity.

To learn more and experience Big Bat Cave through the lidar scans, visit the Kentucky Karst Conservancy online at https://kentuckykarstconservancy.org/.

THE SOUTHEASTERN CAVE CONSERVANCY IN 2019

Christine Walkey[1c]

Southeastern Cave Conservancy, Inc. is the largest land conservancy in the world dedicated solely to the protection of cave and karst ecosystems. SCCi protects wild caves throughout the southeast through conservation, education, and recreation. Our new Director of Education and Outreach, Christine Walkey, will talk about how SCCi achieves its mission. Specific topics include the history and structure of SCCi as a 501(c)3 non-profit organization, current holdings, recent acquisitions, and organizational updates. SCCi has added the Charles B. Henson Preserve at Johnson's Crook, a 2,400-acre property in Rising Fawn, GA. It has also added the Elroy and Marilyn Daleo Cave Preserve, an 85-acre property in Hart County, KY. The Daleo Preserve has an entrance to the Roppel Cave section of Mammoth Cave, the longest known cave on earth. In 2019, SCCi grew by receiving a grant through the Lyndhurst Foundation to support two new staff members, a Land Use Manager and the Director of Education and Outreach. Education has expanded to include the Project Underground curriculum, which is receiving an updated book, website, and educator workshops.

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CHEROKEE SYLLABARY IN HOWARDS WATERFALL CAVE, GEORGIA: CONSERVATION AND INTERPRETATION OF CULTURAL RESOURCES IN A SOUTHEASTERN CAVE CONSERVANCY PRESERVE

Beau Duke Carroll[1], Alan Cressler[2], Stephen Alvarez[3], Tom Belt[4, 5], Jan Simek[6c]

In 2014, Alan Cressler visited Howards Waterfall Cave in Georgia at the request of the Southeastern Cave Conservancy (SCCi). A group had offered to clean "graffiti" from the cave's walls and the SCCi, owners of the cave since 1991, wanted to be sure there was nothing of historical significance on the walls. There was. In a side passage, Cressler saw inscriptions that he recognized as Cherokee syllabary, a Native American writing system invented in the early 19th century by the brilliant Cherokee intellectual Sequoyah. He sent photographs to Simek, who confirmed the identification. Almost immediately, Simek contacted the Eastern Band of Cherokee Indians, and they, along with the US Fish and Wildlife Service, The Conservation Fund, and Transcontinental Gas Pipeline Company, provided funds to build a gate protecting the syllabary passage. Cherokee scholars and others began documentation, translation, and study of the inscriptions, including high-resolution 3D photogrammetric modeling of the syllabary passage by the Ancient Art Archive. Howards Waterfall is one of several caves in the area now known to contain Cherokee inscriptions. The writings in Howards Waterfall Cave concern powerful religious activities that occurred in the seclusion of the cave. The main panel bears a signature in syllabary that has also been documented at Manitou Cave to the south, suggesting the same person participated in ceremonies in both caves. Cherokee syllabary is one of the great intellectual inventions in early American history, and its presence in Howards Waterfall Cave requires special protection and conservation as a rare and significant cultural resource.

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CAVERS CONSERVING KARST: THE INDIANA KARST CONSERVANCY

Salisa L. Lewis[1c], Julian J. Lewis[1]

The Indiana Karst Conservancy (IKC) is a nonprofit organization dedicated to preservation and conservation of caves, springs, and other karst features, including their archaeological, biological, and geological significance. The IKC is organized as a 501(c)(3) nonprofit organization dedicated to the preservation and conservation of Indiana's unique karst features. The organization was formed in 1986 by concerned individuals when it became apparent that no similar group was dedicated to protecting karst in Indiana. An overview of the IKC is available at our website at http://ikc.caves.org/.

Karst protection includes land acquisition, conservation management, research, and education. The IKC pursues targeted acquisitions, with emphasis on sites with high conservation value. For example, the purchase of Upper Twin Cave in the Shawnee Karst Preserve property protects one of the largest known populations of the Indiana Cavefish *Amblyopsis hoosieri* (Fig. 1), along with a variety of other rare subterranean invertebrates. For acquisitions the IKC obtains multiple avenues for funding, frequently partnering with conservation agencies such as The Nature Conservancy and the National Speleological Society. After acquisition, the IKC establishes a stewardship fund, and selects a property manager and a cave patron. The IKC then develops a management plan and liability waiver unique to each property.

Figure 1. Salisa Lewis navigates the deep water of Upper Twin Cave in the IKC Shawnee Karst Preserve (left), and the Indiana Cavefish *Amblyopsis hoosieri* in Upper Twin Cave (right).

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The IKC owns seven cave and spring preserves on more than 250 acres spread across much of the Indiana karst (Fig. 2). These are:

(1) Wayne Cave Preserve, Monroe County
(2) Sullivan Cave Preserve, Lawrence County
(3) Buddha Karst Preserve, Lawrence County
(4) Shawnee Karst Preserve, Lawrence County
(5) Orangeville Rise Nature Preserve, Orange County
(6) Robinson Ladder Cave Preserve, Crawford County
(7) Lowry Karst Preserve, Jennings County

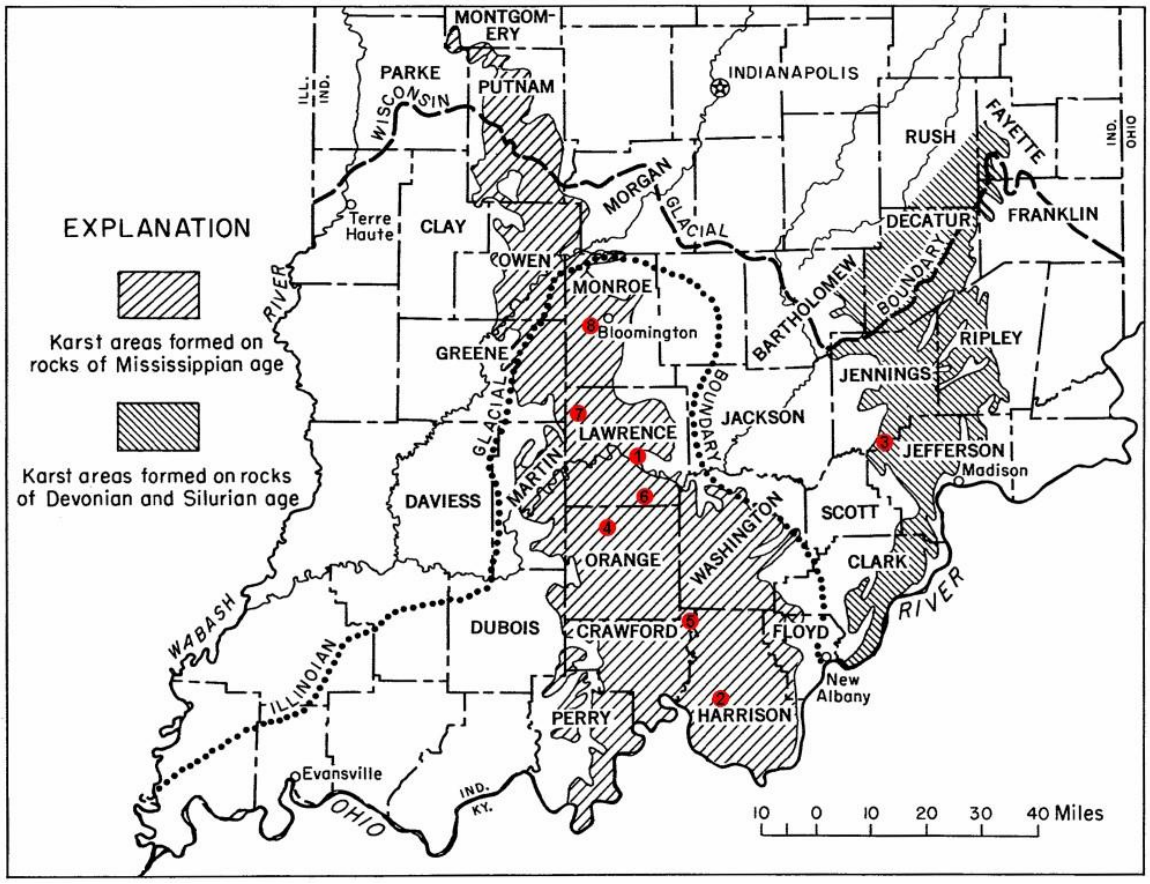

Figure 2. The Indiana Karst Conservancy owns seven properties featuring caves and springs in Monroe, Lawrence, Orange, Crawford, and Jennings Counties, as well as easements on the Sinks of Indian Creek in Harrison County.

The IKC properties are actively managed. When purchased, tracts of ground more often than not exhibit numerous signs of human encroachment on the environment, in the forms of deforestation, abandoned buildings, dumps, and a prevalence of invasive plants. At the time of acquisition, the Buddha Karst Preserve was mostly fescue fields. Purchased in 2001, volunteers participated in annual spring work days for several years planting several thousand trees, ranging from oaks to persimmons to dogwoods (Fig. 3). Subsequently a grant was obtained for

mechanical planting of the remaining part of the property, with the result that the entire preserve has over 10,000 trees planted and is well on its way to reforestation. At the Robinson Ladder Cave Preserve, partnership with the American Chestnut Foundation has provided for planting of chestnut trees with significant immunity to the Chestnut blight that erased the trees from our landscape.

Figure 3. Tom Sollman hand plants a tree at Buddha Karst Preserve in 2008 (left), and a team of IKC volunteers working together to demolish an abandoned trailer in 2000 at the Sullivan Cave Preserve (right).

Seemingly all properties have one or more abandoned buildings present at the time of acquisition. It has become a point of humor that the IKC has specialized in removing old house trailers, as well as houses and other buildings (Fig. 3). At the Shawnee Karst Preserve the house had already been demolished . . . and dumped into the sinkhole containing the entrance to Upper Twin Cave. Over the course of five work days, the remains of an entire farm house was removed from the sink and taken away for recycling or placement in a proper landfill.

Non-native invasive plants are a major problem in land management in southern Indiana. Volunteer work days are organized several times each year for the purpose of removing invasives to allow the native forests to thrive. Exotic plants removed include autumn olive, bush honeysuckle, Japanese honeysuckle, burning bush, and multiflora rose, among others. After acquisition of a property it is not unusual to find exotic plants that have grown so out of control that they must be cut with a chainsaw. The stumps are treated with application of undiluted glyphosate herbicide to discourage regrowth. After initial management, volunteers with loppers can cut and herbicide smaller invasives trying to re-establish footholds. It's a never-ending battle.

Extensive areas of native prairies in the form of glades and barrens were historically part of the southern Indiana landscape. Two of the IKC properties, Robinson Ladder Cave and Shawnee Karst Preserves, have areas containing native warm-season grasses, like Indian

grass, and other prairie plants. Management of these areas include periodic hand removal of encroaching red cedar trees as well as prescribed burns.

Through partnerships with state and private landowners, the IKC manages several additional conservation easements and karst properties, including the Sinks of Indian Creek (Harrison County), Suicide Cave (Washington County), and Shiloh Cave (Lawrence County). The management of the caves entails gating and control of visitation. At the Sinks property, where the entirety of Indian Creek flows underground as a major component of the largest spring in Indiana (Harrison Spring), the IKC manages several conservation easements initiated by The Nature Conservancy. This property has been subdivided and proves to be a challenge to manage. One owner constructed a large picnic shelter on the conservation easement and the IKC was obliged to insist on the removal of the structure.

The IKC pursues opportunities for karst conservation through community outreach and education. Examples of this include newsletters, caving opportunities for grottos, and cave trips to encourage environmentally compatible use. Meetings and partnerships with state, federal, and local agencies offer opportunities for land management, research, and education. Education, outreach, and karst management are positive activities supporting cave conservation. These activities encourage member participation. One of our historical highlights was organizing and hosting the 1995 National Cave Management Symposium at Spring Mill State Park.

Some of the challenges with land management facing the IKC have been mentioned. Others include the ever-present issues associated with liability, vandalism, and trespassing.

Luckily, although the IKC has had to deal with problems created by people, they are relatively infrequent and solutions have prevailed. At times the fight against a hostile environment has created challenges as well, as the entrance to Upper Twin Cave has collapsed on two occasions requiring mechanical excavation to reopen it. At Buddha Cave, a large ledge used for access into the main part of the cave collapsed, probably due to natural frost spalling around the entrance, so that a ladder is now necessary to enter.

Like other similar organizations, maintaining our membership as well as the leadership needed for the board of directors requires recruitment, with subsequent member engagement to succeed in retention. A major area of opportunity for member recruitment is outreach and collaboration with grottos, clubs, and other groups interest in caves and conservation. Beyond our own organization we network with a spectrum of people, from cavers to members of other cave and karst conservancies. So where better to find an excellent forum for discussion to further the cause of cave and karst conservation than the National Cave and Karst Management Symposium!

A UNIFIED INTERDISCIPLINARY APPROACH FOR THE PROTECTION OF KARST AQUIFERS

Katarina Kosič Ficco[1c], Ira D. Sasowsky[2]

Generalization of karst aquifer protection continues to present a challenge. Karst aquifer assessment and management require site-specific approaches due to the varying character and extreme susceptibility to contamination of these aquifers. Interjurisdictional protection can be hampered by confusing methodologies and guidelines that result from a lack of cooperation between stakeholders and differences between regulatory and legislative systems.

Analyses of socio-political and scientific aspects have shown that thorough protection of karst aquifers can only be assured if these two perspectives are combined (Kosič Ficco, 2019). Although the implementation of appropriate scientific methods is of extreme importance (Ford and Williams, 2007; Goldscheider and Drew, 2007; Krešić, 2013; Stevanović, 2015), studies of legislative and scientific aspects of karst aquifer protection have shown that the inclusion of a wider range of stakeholders can greatly improve outcomes (Kosič Ficco and Sasowsky, 2018; Kosič Ficco, 2019). Relevant stakeholders include karst experts, other scientists, regulators, elected officials and policy-making bodies, individual citizens, businesses, and nongovernment organizations. These entities bring knowledge and information that can expedite the evaluation of karst terrains and development of suitable management practices (Jiménez-Madrid et al., 2012; Kosič Ficco and Sasowsky, 2018).

The K-framework (Table 1) is a new approach to karst aquifer protection and management that was developed to address these issues. The K-framework is both generalized and interdisciplinary. It assigns stakeholders to different levels based on the type and degree of knowledge and information that they can contribute to the development of karst protection strategies and policies.

The K-framework provides step-based guidelines (Table 2) for carefully structured cooperation between stakeholders involved in karst aquifer protection. As thoroughly described in Kosič Ficco and Sasowsky (2018) and Kosič Ficco (2019), combining these different levels enables developing site-specific assessment guidelines for individual karst aquifers as well as protection policies on the national and international levels. The general nature of the K-framework allows it to be implemented across diverse karst terrains for evaluating aquifer risk and mitigation strategies associated with a wide variety of proposed development activities. It can be used regardless of the regulatory environment, terrain, and hazards. By implementing the straightforward approach of the K-framework, the management and protection of karst aquifers can be significantly improved.

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Table 1. Levels of knowledge used for K-framework.

Level	Domain/Participant	Contribution
K1	Members of the general public including land-owners, public water supply consumers, cavers, et cetera.	Inform participants at other levels about local karst and other natural phenomena and features. Help define the public interest in terms of needs and expectations.
K2	Managers and scientists from various fields (hydrology, geology, biology, et cet.) with no specific karst related training. May represent government agencies, environmental and conservation organizations, urban and spatial planning agencies, consulting environmental agencies or businesses.	Provide expertise about the management of the area; inform about local karst phenomena and features. Provide scientific findings regarding geology, hydrology, biology, et cetera of area. Communicate with residents (K1). Perform karst related monitoring in cooperation with karst scientists, as presented in Table 2.
K3	Karst scientist managers with a comprehensive understanding of karst functioning and the ability to communicate their knowledge to non-experts in educational, political, and managerial roles.	“Translate” karst science to scientists from other disciplines and to participants from non-scientific realms. Educate and communicate with stakeholders, policy-makers, and potential managers of karst areas.
K4	Karst scientists, e.g., geologists, hydrogeologists, speleologists, biologists, and other experts in the field.	Perform field observations, evaluations, and monitoring in cooperation with and under the direction of K3.

Table 2. K-framework for Karst Aquifer Protection.

Step	Procedure	Domain
1	Geologically evaluate the area and identify karst features (using existing databases and performing onsite evaluations).	Karst scientists (K4)
2	Speleologically evaluate the area (using existing databases and performing onsite evaluations).	Karst scientists (K4)
3	Evaluate karst aquifers (using existing databases and performing on-site evaluations).	Karst scientists (K4)
4	Evaluate species in the caves and aquifers to define their vulnerability (using existing databases and performing onsite evaluations).	Karst scientists (K4)
5	Assess hazards (using existing databases and performing on-site evaluations).	Cooperation among karst scientists from various fields (K3 and K4)
6	Develop report presenting vulnerability and characteristics of the area.	Karst scientists (K3 and K4)
7	K3 presents findings and communicates with policymakers and the public in order to gain more information from K1 regarding the area and missed karst features.	Karst scientist manager (K3); Public (K1)
8	Based on the above, K3 and K4 perform supplemental investigations if needed.	Cooperation between karst scientists (K3 and K4)
9	Develop an extended report with guidelines for monitoring, preservation, and management. Include information from the public hearing and supplemental investigation.	Karst scientist manager (K3)
10	Present proposed approaches to policymakers and the public.	Karst scientist manager (K3)
11	Perform monitoring and managing the data.	Environmental agencies or dedicated karst department (K2 or K3 and K4)
12	Analyze the data.	Karst scientists (K3 and K4)
13	Prepare reports for environmental agencies.	Karst scientists/Karst scientist manager (K3/K4)
14	Manage the area based on provided guidelines.	Agency or landowners responsible for the management (K2 and K1)

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IMPROVEMENTS FOR ACCESS TO EDGEWOOD CAVERN IN CENTRAL NEW MEXICO

John T. M. Lyles[1c]

In 1970, a cave was discovered by a well driller in Edgewood, 30 minutes east of Albuquerque, NM, in the Pennsylvanian Madera limestone, which occurs only in the subsurface in the area and which commonly produces blowing wells when penetrated by drilling. The landowner and driller dug a shaft using a cable tool rig and a large homemade bit. This 38-meter deep shaft was cased, and cavers were called in to dig into the passages beyond a blowing crack at the bottom. Eventually, they succeeded and Edgewood Cavern became a local curiosity. Though the owner continued into the current millennium to market 5 acres with the cave for one million dollars, it never became the commercial enterprise he hoped for. The 0.5 m (19.5 in) diameter entrance shaft didn't help, although visions of billboards along I-40 kept the dream alive. Cavers explored and mapped about 5 miles of passages, finding extensive joint-controlled morphology and significant fossil exposures. The cave was always at risk from renters and was a safety concern. The author became interested in 2002 and worked with the owner to obtain limited access. Newspaper reports and published scientific work (e.g. Polyak and Asmerom, 2005) resulted from the renewed interest. In 2017, the landowner transferred ownership of the property to the author. Since 2018, there has been significant work cleaning up the property, fencing, and building a permanent structure over the entrance of the cave for further protection. The author (landowner) will continue to permit opportunities for cave science and exploration.

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KARST IN PERRY COUNTY

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Perry County, Missouri has over 700 documented caves, including four of the state's five longest caves. The intense surface karst includes vast areas of subterranean drainage with numerous sinkholes, caves, and springs. The caves host great biodiversity, including the federally endangered grotto sculpin (*Cottus specus*). The chief threat to the sculpin is water quality and habitat loss. The City of Perryville is a rapidly growing community with numerous industries. Over time, the city has taken steps to ensure that cave systems under the city and surrounding areas have their watersheds improved and protected. Caving organizations and other non-governmental organizations have helped as have state and federal agencies. Today, while there is much more to be done, the outlook for the grotto sculpin and the caves in general is improving. This educational video shows how human adaptations to the karst environment have changed over time. In the nineteenth century, residents used sinkholes as sewers and later as trash receptacles. In recent times, the local community has come to value water quality in the cave streams and springs, and has turned a controversy over the endangered grotto sculpin into proactive efforts to prevent sediment and agricultural chemicals from entering groundwater and caves.

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NEW RIVER CAVE USAGE: THE SPELUNKER AND HIS TOOLS

Taren Woelk[1c]

Abstract

The purpose of this study was to establish usage rates of the National Speleological Society (NSS) New River Cave Preserve and to use this information to determine the relative safety of users and potential threats to the cave's resources. It has been known by preserve managers and supporting grottos that the Preserve has been heavily visited by inexperienced visitors. In recent years, the cave's location has become well publicized on the internet. It is believed that this has increased the number of underprepared visitors. In order to research these questions, I have been collecting data from trail camera images from 9/15/2018 through 3/15/2019. From these images, I derive the length of a trip, the number of participants, their clothing quality, the presence of a helmet and lights, and any inclement weather. Furthermore, I reached out to Preserve Managers of other NSS properties to ascertain possible conditions of heavy usage by non-cavers at their locations. From this analysis, I was able to determine that the large portion of visitors to the New River Preserve do not have proper equipment during any time of year, but during cold winter months are more likely to be properly clothed for caving due to outside weather conditions. The vast majority of these visitors seem to be college students. Additionally, it was found that many large trips (exceeding 15 persons), sometimes multiple in a day, visited the cave during hibernation season. The results of this study suggest that both the users and the cave are at risk of harm and it is recommended a waiver and permit system be introduced, and potentially a gate in the future if the aforementioned techniques fail.

Introduction

Located in Giles County, Virginia, New River Cave Preserve has had a long history of visitation, although a small portion of that has been while under the ownership of the NSS in 2014. The property was owned by a mining and timber company from 1928 until 1989, when it was purchased by caver Tim Kilby. Kilby allowed visitation under the condition of a waiver being signed and kept in his own files. Kilby was in general an absentee landowner and unauthorized visits to the cave, sometimes resulting in lost or injured spelunkers, were common. In 2014, the NSS purchased the property from Mr. Kilby and allowed visitation without the signing of a permit or waiver.

The only official records currently being kept at the Preserve are at two voluntary registers, one at a kiosk, and the other inside the cave. These are monitored by the VPI Cave Club. The property has been managed by at least one Preserve Manager since the acquisition from Mr. Kilby. Since the NSS took ownership, improvements to the Preserve consist mainly of a new, safer and more accessible trail and the addition of the aforementioned informational kiosk. While these improvements have increased accessibility for cavers, it is also possible they have encouraged use by non-cavers. We were unable to explore this possibility due to a lack of historical knowledge about user visitation.

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The purpose of this study was to gain more in-depth knowledge of visitation, and to use it to help form policies and procedures for both the NSS as a whole and at the level of the Preserve Manager. I could find no pre-existing research on recreational wild cave visitation. The original assumption for this case was that the majority of visitors would be underprepared (e.g. no helmet or light, inadequate clothing) and of college age. This seemed likely due to the cave's word-of-mouth popularity on the nearby Virginia Tech campus and previous experiences of cavers in the community.

Methods

A trail camera was placed facing the Preserve kiosk (Fig. 1) from 9/15/2018 until 3/15/2019, with images retrieved from the camera's SD memory card and batteries replaced monthly. The images were then transferred to a USB thumb drive that held all of the project's data. The images were individually processed to remove irrelevant images (moving branches, animals, etc.). The remaining images were assessed for the following information, which was stored in a spreadsheet by trip number with entries for each individual visitor: date, time into cave, time out of cave, presence of a helmet, presence of a light, adequacy of clothing, sex, race, approximate age, and presence of inclement weather. Specifics of data representation were:

Presence of a helmet or light = 2, None = 1
Sex: Male = 1, Female = 2
Race: White = 1, Black = 2, Asian = 3
Approximate Age: Child = 1, College-aged = 2, Adult = 3, Elderly = 4
Clothing: Scale of 1–5, with 1 being very underprepared
Presence of inclement weather = 1, None = No Value
Data could not be determined = 0

Analysis was run on the 150 trips, and 634 individuals, and the results were presented at the 2019 NSS Convention and the 2019 National Cave and Karst Management Symposium.

Figure 1. View of kiosk and visitor from trail camera

Results

After running analysis, the following information and statistics were determined:

Longest trip: 8 hours, 22 minutes*
Average duration: 3 hours, 14 minutes
Average duration without helmets: 1 hour, 43 minutes
Largest trip: 18 persons
Helmet Average: 58.7%
Light Average: 90% or 74%
Clothing Average: 4.49 (well prepared)
Age Class Average: 2.19 (young adults)
Sex Average: 1.32 (male)
(* - a trip of 33 hours 35 minutes duration was also recorded, and was due to lost cavers and a near rescue.)

Additionally, 69% of trips took place on a weekend (Saturday/Sunday).

Discussion

Several of the results of this research were surprising. Originally, it was assumed that the percentage of visitors using helmets would be more in the range of 25%; however, analysis yielded more than double that rate. Additionally, the rate of users with lights was higher than expected, as known cavers frequently recalled running into many trips using only cell phones as light. This rate was much harder to calculate, however, than for the helmets. This was due to the small size of lights and ease of concealment in a pocket, bag, etc. The 90% figure was calculated by using only instances where it was clear if the visitor did, or did not, have a light. The 74% figure includes instances where light presence was unknown, and therefore assumed to not be present. One reason for these higher than expected rates of helmet and light use is likely large professional recreational trips, where participants are provided safety equipment.

The average for adequacy of clothing was also higher than expected, likely due to the fact that data were collected during winter, when visitors were already more inclined to be wearing long sleeves, pants, and layers. Inclement weather proved to be so rare during recorded trips that its statistics were negligible.

Technically, the longest trip of 33 hours 35 minutes is due to a near rescue of two lost individuals who were found by chance by participants on a subsequent trip into the cave. The longest presumably intentional recorded trip was 8 hours and 22 minutes, and is reflected as the longest trip in the table of results. The average trip durations of those with versus without helmets is meant to indicate average trips times of experienced versus inexperienced visitors. It was found that if an individual had a helmet, they always had a light, and generally had proper clothing, making it a good indicator of proficiency. Finally, the data confirm the assumption that the majority of visitors were college-aged, with the strong majority being white males.

Conclusions

The information yielded through regular monitoring of the trail camera proved to be invaluable as a management tool for the property. It provided great insight into usage demographics and patterns at a relatively low operating cost, especially considering rechargeable batteries were used. The data yielded was surprising in that it sometimes contradicted expectations, such as with the rates of helmet use and appropriateness of clothing. Further research across different

seasons and with consideration for recreational groups' scheduling would be necessary to be more definitive with these results. Due to the unexplored nature of the topic of cave visitation, there are plenty of opportunities for continued research.

It was concerning to see such high numbers of visitation throughout the winter, due to the cave's hosting of a large number of bats over the hibernation season (late October through April). In regards to management measures, the reinstitution of a waiver system, with the addition of trip by trip permits is recommended. If, after some time, this is found to be ineffective, gating may be considered after more research.

Additional support was provided by Stewart Scales of the Virginia Tech Department of Geography and Philip Balister of OpenSDR.

HYDROLOGIC CONNECTIONS BETWEEN PRECIPITATION, DRIPWATER AND STREAM DISCHARGE IN JAMES CAVE, VIRGINIA

Megan Junod[1c], Madeline Schreiber[1], Katarina Kosič Ficco[2], Thomas Malabad[2], Wil Orndorff[2]

In 2007, we instrumented James Cave in Pulaski Co., Virginia to study the hydrologic connections between precipitation, dripwater and the cave stream with the goal of delineating mechanisms and quantifying rates of recharge to the karst aquifer. Currently, we have collected almost 12 years of high-frequency measurements, including relative dripwater rates and absolute stream discharge. Dripwater rates are measured on 10-min intervals using suspended tarps draining to rain gauges. Stream discharge is calculated using pressure transducers that log stream depth behind a V-notch weir. For this project, we compare the datasets of precipitation, dripwater rates and stream discharge rates to evaluate hydraulic connections and patterns of recharge. From 2007 to 2018, aquifer recharge occurred only during 3 to 5 month periods ending each May. In 2018-19, a year with record precipitation, recharge lasted over 8 months. We are also evaluating connections between precipitation, dripwater rates and stream discharge to compare patterns of diffuse and direct recharge. Another goal of this project is to create and maintain a long-term cave hydrology dataset in the public domain. To do this, dataloggers in the cave are downloaded monthly to bimonthly and are processed through instrument software (Hoboware) to screen for data quality and to check for instrumentation failure. After processing, datasets are merged using either time series software or R. All raw and processed data are maintained in shared folders in the cloud. Data are periodically published and made available to the public via VTechWorks, a Virginia Tech data repository.

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CAVE MANAGEMENT LAW, POLICY AND IMPLEMENTATION IN THE PHILIPPINES

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The Republic of the Philippines has a robust cave and karst management system that can be a model for other nations seeking to protect and manage their cave and karst resources. The Philippine program is based upon the federal Cave and Karst Management Protection Act of 2001 (CKMPA), which is closely linked to other laws including the Indigenous People's Rights Act of 1997, the National Integrated Protected Areas System Act of 1992 and the Tourism Act of 2009. CKMPA is administered by the Federal Department of Environment and Natural Resources (DENR). DENR has developed cave assessment and classification systems and cave conservation and management handbooks, and trained staff in their use and implementation. Information on caves is restricted until assessments have been completed. Philippine and foreign cavers are heavily involved in the implementation of the law and policies. As is true in most countries, there remains a shortage of staff, finances, and other resources to strongly implement all aspects of a cave and karst program.

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HOW IMPORTANT ARE GROTTOES TO LANDOWNER RELATIONS?

Tom Griffin[1c]

While nearly all organized American cavers belong to the National Speleological Society (NSS), Grottoes are the local organizational units (essentially chapters of the NSS) with which most cavers identify. One important role a Grotto can fulfill is that of liaison between cavers and landowners. I would like to go over guidance on how best to first approach a landowner regarding access and other cave-related issues, and on how to follow up and maintain good landowner relations. The NSS landowner relations committee is developing this guidance as a tool that can be used by Grottoes around the country to help improve and maintain landowner relations.

One way the VPI Cave Club (Virginia Tech) fosters good landowner relations is by completing a road cleanup twice a year in a popular caving area. (Photo by Wil Orndorff)

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ENDANGERED SPECIES MANAGEMENT IN AN ERA OF EVER-INCREASING BIODIVERSITY: A CASE STUDY OF THE MOLECULAR PHYLOGENETICS OF *LIRCEUS HARGERI*

Julian Lewis[1c], Salisa Lewis[1], William Orndorff[2], Florian Malard[3], Christophe Douady[3], Lara Konecy[3]

In 2015 there were two species of the freshwater isopod *Lirceus* reported from Lee County, Virginia: (1) the Lee County Cave Isopod *Lirceus usdagalun,* an eyeless, unpigmented obligate cavernicole (Fig. 1); and (2) Harger's Spring Isopod *Lirceus hargeri,* an eyed, pigmented inhabitant of springs. *Lirceus usdagalun,* described by Holsinger and Bowman (1973), was placed on the U.S. Fish and Wildlife Service list of federal endangered species in 1992 (U. S. Fish and Wildlife Service, 1992). As an endangered species, the Lee County Cave Isopod received intensive sampling attention to discover new populations and further establish its range. *Lirceus hargeri* was described by Hubricht and Mackin (1949) and reported from a spring in Lee County and three springs in adjacent Tennessee. The description was too poor to characterize the species, which remained in obscurity. The only other species of *Lirceus* known from southwestern Virginia was *Lirceus culveri*, another stygobiontic isopod described from a cave in the Rye Cove area of neighboring Scott County (Estes and Holsinger, 1976). Holsinger and Bowman (1973) listed other collections of *Lirceus* as "species A and species B," as they were unable to identify them further.

In 2016, as part of a revision of the genus *Lirceus* (Lewis and Lewis, in preparation), Julian Lewis conducted a 3-week visit to the Smithsonian Institution for the purpose of preparing re-descriptions from the type-specimens of all of the known species. Leslie Hubricht had deposited the type-specimens of most of the species described in the 1949 *Lirceus* monograph (Hubricht and Mackin, 1949) in the collection of the National Museum of Natural History, where they resided at the Smithsonian Museum Support Center. For the new revision of the genus, the type-specimens of *Lirceus hargeri* were examined, and Lewis immediately realized that the genital pleopod morphology of this spring species was nearly identical to that of *Lirceus usdagalun* and *Lirceus culveri* (Lewis et al., 2017). Examination of numerous other collections at the Smithsonian revealed the range of the morphospecies *Lirceus hargeri* extended from southwestern Virginia through eastern Tennessee into northern Georgia (Lewis et al., 2017).

A new collaboration with French colleagues at the University of Lyon for molecular phylogenetic analysis spurred collection of fresh specimens from across the range of the problematic *Lirceus hargeri*. In 2017, the senior author conducted a collecting trip of almost 2,000 miles, starting in the northern Appalachians, then going southward following the karst of the Appalachian Valley.

This trip first produced freshly preserved specimens of *Lirceus brachyurus* from central Pennsylvania, western Maryland, eastern West Virginia, and the adjacent part of Virginia. Next, continuing into southwestern Virginia, Tennessee, and northern Georgia, many collections were made of *Lirceus hargeri* s. latu.

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Figure 1. The Lee County Cave Isopod (*Lirceus usdagalun*), a stygobiont, and Burn's Spring Isopod (*Lirceus* undescribed species), from Cardwell Spring, Grainger County, Tennessee. Animals are ~ 5 to 7 mm in length.

The aim of the 2017 collecting trip was a sampling resolution of one collection per county. In southwestern Virginia emphasis was placed on re-visiting sites listed in Holsinger and Bowman (1973), such as the caves in Ward Cove, Tazewell County, from which Orndorff's Cave Isopod is now being described (Fig. 2).

The specimens were then shipped to Lyon, where DNA was extracted and multiple genes (e.g., 16S, CO1, et al.) were sequenced. Prior to receiving the results of the molecular analyses, Lewis et al. (2017) had proposed the designation of six subspecies (morphospecies) within *L. hargeri*. However, based on the subsequent DNA sequencing, a polytypic species concept for *Lirceus hargeri* was rejected. Consistent, systematic, and significant differences across multiple genes among the three described taxa (*L. hargeri, L. usdagalun*, and *L. culveri*) suggested they were indeed valid species. Furthermore, the molecular analyses revealed the presence of many more molecular operational taxonomic units (MOTUs, Blaxter et al. 2005) across the range of the *hargeri* morphospecies. For purposes of this paper, we will assume that the MOTUs are likely to correspond to biological species consistent with the observations of Blaxter et al. (2005). The realization dawned that *Lirceus hargeri* was more likely a species group rather than a single polymorphic species, and that almost every collection potentially represented a new species.

Figure 2. The large stream issuing from Hugh Young Cave, part of the Ward Cove-Maiden Springs groundwater basin inhabited by Orndorff's Cave Isopod (*Lirceus* undescribed species).

In 2018 another shorter sampling trip was conducted in southwestern Virginia and adjacent northeastern Tennessee with the goal of collecting isopods from previously unsampled counties. Again, every site sampled revealed more undescribed species in the *hargeri* species group. Most recently, in 2018, multiple caves and springs in Lee and Scott Counties, Virginia, were sampled with the revelation of even more undescribed *Lirceus*. To date, at least 25 MOTUs have been discovered (Table 1), by far the highest concentration of genetic diversity known among any of the species groups of North American asellid isopods. In contrast, *Lirceus brachyurus* specimens collected throughout the Chesapeake Bay watershed from central Pennsylvania through Maryland, West Virginia, and northern Virginia appear essentially uniform from a genetic standpoint—one clade representing collections spread across the entire range with the exception of a second clade representing an undescribed species known only from the thermal spring at Berkeley Springs, West Virginia.

This phenomenal biodiversity is likely a product of the geography of the Mountain Empire region of southwestern Virginia and adjacent Tennessee, which has produced many opportunities for allopatric speciation. The greatest number of MOTUs within the *Hargeri* species group has been discovered where the Tennessee River divides into valleys formed between the Powell and Clinch mountains (Fig. 3). These mountains are discrete ridges of largely non-carbonate bedrock that extend almost continuously for tens of miles from southwest to northeast. As such, these ranges are formidable dispersal barriers to aquatic isopods, isolating them in river valleys between mountains. The valleys are predominantly floored with limestone. Caves and springs

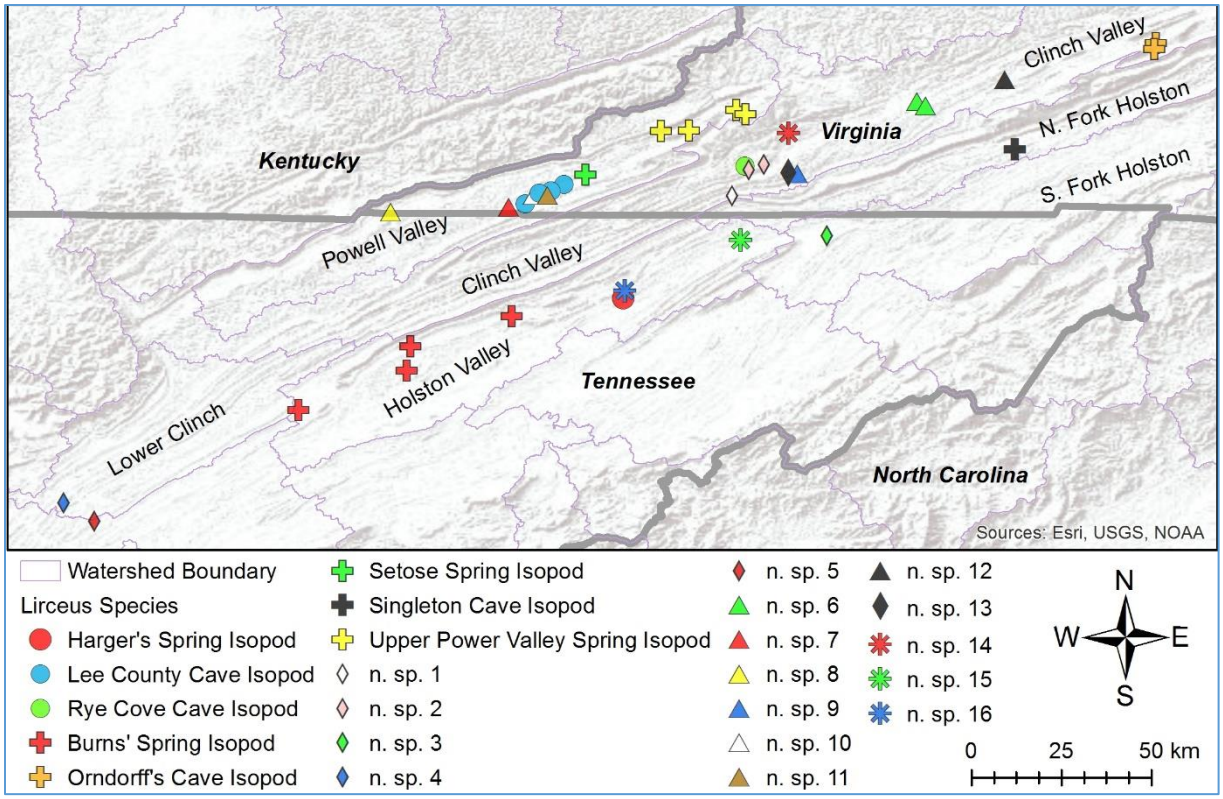

Figure 3. Known locations of 25 species in the *Lirceus hargeri* group, northeastern Tennessee and southwestern Virginia (Peck's Spring Isopod not shown, occurs to the southwest in the Chattanooga, Tennessee, area).

are ubiquitous. The rivers bifurcate dendritically, forming dozens of isolated cold-water spring runs. In some instances, *Lirceus* has invaded cave waters producing more instances of speciation with varying degrees of troglomorphism from one cave system to the next. Although most springs sampled are inhabited by a representative of the *Lirceus hargeri* complex, many caves have only *Caecidotea* spp. In caves where a stygobiontic *Lirceus* is present, there is usually a species of *Caecidotea*, although the two genera do not always occupy the same specific habitat. The degree to which *Lirceus* spp. have invaded cave streams likely depends on the ability to compete with the widespread *Caecidotea* spp., and may be a function of the hydrologic conditions of specific cave systems.

The characterization of the *Lirceus hargeri* complex taxa is two-pronged. After collection, the specimens are examined and identified (many species of other genera are also being collected so identification is not a foregone conclusion). Next the specimen collections are divided, with part shipped to the University of Lyon for molecular genetic analysis, with the rest retained for morphological description. In Lyon the specimens are examined and three individuals from each locality (preferably males) are selected for DNA extraction and sequencing. Each of the three specimens are dissected and photomicrographs of pleopods 1–5 are made for future reference if the morphological identification comes into question. A pereopod from each specimen is then

sacrificed for analysis. Multiple primers are used to obtain sequences for several genes. After the sequences are available, the last step is the phylogenetic analysis.

Parallel to the work in Lyon, progress is being made understanding how the MOTUs might translate into morphological species. In other situations, species descriptions are based primarily on differences in the genitalia that are customarily relatively apparent. That is not the case with describing species of the *Lirceus hargeri* group since the genitalia, i.e. the male second pleopod endopodite tip, are more or less identical. Among other animals, MOTUs have not always corresponded 1:1 with morphological species, for example in the benthic meiofauna (Blaxter et al., 2005.) Nonetheless, MOTUs have proven valuable in identifying diversity and indicating potential species. Descriptions of new morphological species in this complex require scrutiny of specimens to discern morphologically distinctive characteristics. Unique features have proved to be present suggesting that in this case the MOTUs do indeed reflect the presence of multiple cryptic species. Descriptions have been prepared for new species of two stygobiontic and three spring-inhabiting *Lirceus* (Lewis and Lewis, in preparation): (1) Singleton Cave Isopod—Singleton Cave, Washington County, Virginia; (2) Orndorff's Cave Isopod—Ward Cove/Maiden Springs groundwater basin, Tazewell County, Virginia; (3) Setose spring isopod—Crockett Spring, Lee County, Virginia; (4) Burn's Spring Isopod (Fig. 1)—Grainger and Knox counties, Tennessee; and (5) Peck's Spring Isopod—Hamilton County, Tennessee, and adjacent Georgia.

The new challenge is how to manage this complex of species with the realization that several of them are rarer, and more vulnerable, than the listed endangered species. The stygobiontic Singleton Cave Isopod, known only from specimens collected by Dr. John Holsinger in 1967, has apparently already been extirpated from the one remote cave where it was found (multiple attempts to find more specimens have been fruitless). Of the other taxa of the *Lirceus hargeri* species group, the majority are considerably rarer than the endangered Lee County Cave Isopod (see comparison of number of known localities in Table 1). Most of these taxa are known from single sites with the prominent possibility that species like the Flanary Bridge Spring Isopod are endemic to spring runs only measuring a few meters in extent.

Table 1. The known taxa of the *Lirceus hargeri* species complex suggested by MOTUs identified by DNA sequencing. Described species are named in parenthesis, and species for which morphological descriptions have been prepared are indicated with an asterisk.

Designation	State	Counties	River basin	Popu-lations
Harger's spring isopod (*Lirceus hargeri*)	TN	Hawkins	Holston	2
Lee County cave isopod (*Lirceus usdagalun*)	VA	Lee	Powell	4
Rye Cove cave isopod (*Lirceus culveri*)	VA	Scott	Clinch	1
Alley Valley spring isopod (n. sp. 13)	VA	Scott	Clinch	1
Bacon spring isopod (n. sp. 7)	VA	Lee	Powell	1
Big Spring isopod (n. sp. 6)	VA	Russell	Clinch	2
Brickey Spring isopod (n. sp. 14)	VA	Scott	Clinch	1
Burn's spring isopod*	TN	Grainger, Knox	Holston	4
Carter Big Spring isopod (n. sp. 5)	TN	Loudon	Tennessee	1
Church Hill spring isopod (n. sp. 15)	TN	Hawkins	Holston	1
Crockett cave isopod (n. sp. 16)	TN	Hawkins	Holston	1
Flanary Bridge spring isopod (n. sp. 11)	VA	Lee	Powell	1
Gilmer’s spring isopod (n. sp. 12)	VA	Russell	Clinch	1
Kingsport spring isopod (n. sp. 3)	TN	Sullivan	Holston	1
Lower Powell Valley spring isopod (n. sp. 10)	VA	Lee	Powell	1
Mill Creek spring isopod (n. sp. 2)	VA	Scott	Clinch	1
Orndorff's cave isopod*	VA	Tazewell	Clinch	1
Peck's spring isopod*	TN GA	Hamilton (TN) Catoosa (GA) Dade (GA) Walker (GA)	Tennessee	6
Poplar Spring isopod (n. sp. 4)	TN	Roane	Clinch	1
Quillin Spring isopod (n. sp. 9)	VA	Scott	Clinch	1
Setose spring isopod*	VA	Lee	Powell	1
Singleton Cave isopod*	VA	Washington	Holston	1
Speers Ferry cave isopod (n. sp. 1)	VA	Scott	Clinch	1
Upper Powell Valley spring isopod	VA	Lee, Wise	Powell	6
Young-Fugate spring isopod (n. sp. 8)	VA	Lee	Powell	1

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USE OF DYE TRACING TO DELINEATE THE RECHARGE AREA OF MANITOU CAVE, ALABAMA, TOWARDS ASSESSING SENSITIVE STYGOBIONT HABITAT

Benjamin Verlinden Miller[1c]

Abstract

In 2010 the U.S. Fish and Wildlife (USFWS) was petitioned to federally list the Manitou Cavesnail, (*Antrorbis breweri*), a stygobiont endemic to Manitou Cave in northwestern Alabama, as an endangered species. When the USFWS is tasked with determining whether to list a species under the Endangered Species Act, one of the components examined is any potential threats to the biota. Knowing the recharge area for a cave or spring is critical to identifying potential threats because of the interconnectivity between surface activities and groundwater quality/quantity in karst areas. The 1.7-km-long cave is currently owned by a nonprofit organization, Manitou Cave of Alabama, which oversees management, restoration, research, and documentation activities. In 2019, a cooperative project between USFWS and the U.S. Geological Survey was initiated to delineate a recharge area for Manitou Cave through dye tracing. From June through November 2019, two rounds of dye injections were conducted at a total of eight individual dye injection locations. A network of 24 monitored locations utilized charcoal packets in order to detect dye at major springs, caves, and surface streams. Following the study, two positive traces to Manitou Cave helped to delineate a recharge area for the cave totaling 1.22 km^2. The current research will be used by USFWS to determine primary threats and to inform the decision of whether and how to list the Manitou Cavesnail under the Endangered Species Act. Potential threats to water quality and quantity in the Manitou Cave recharge area include recent subdivision developments, a nearby active quarry, land clearing, and several major highways.

Introduction

Cave biota exhibit a higher rate of endemism than do species in most other ecosystems, a result of isolation and other conditions that are unique to cave and karst environments. The "TAG" area of the Cumberland Plateau, where Tennessee, Alabama, and Georgia share a common border, is a documented hotspot for biodiversity in subterranean environments (Christman and Culver, 2001; Culver et al., 2006). The cave and karst systems of the Cumberland Plateau are highly connected to the surface environment due to numerous sinking streams draining the escarpment of the plateau (Crawford, 1987). In such an interconnected system, the water quality and quantity in cave streams is strongly influenced and can be impacted by activities that occur in the watersheds of sinking streams. Thus, when trying to protect sensitive cave organisms, particularly aquatic cave biota or stygobionts, it is crucial to identify the recharge areas that supply water to such species' habitats.

Manitou Cave, a 1.7-km-long stream cave (Guy, 2009a) in northeastern Alabama, is the only documented habitat for the Manitou Cavesnail, *Antrorbis breweri* (Herschler and Thompson, 1990). The snail is a small (2–3 mm) stygobiont that lives on cobbles in riffle areas of the cave stream (Fig. 1). In 2010, the Center for Biological Diversity petitioned the U.S. Fish and Wildlife

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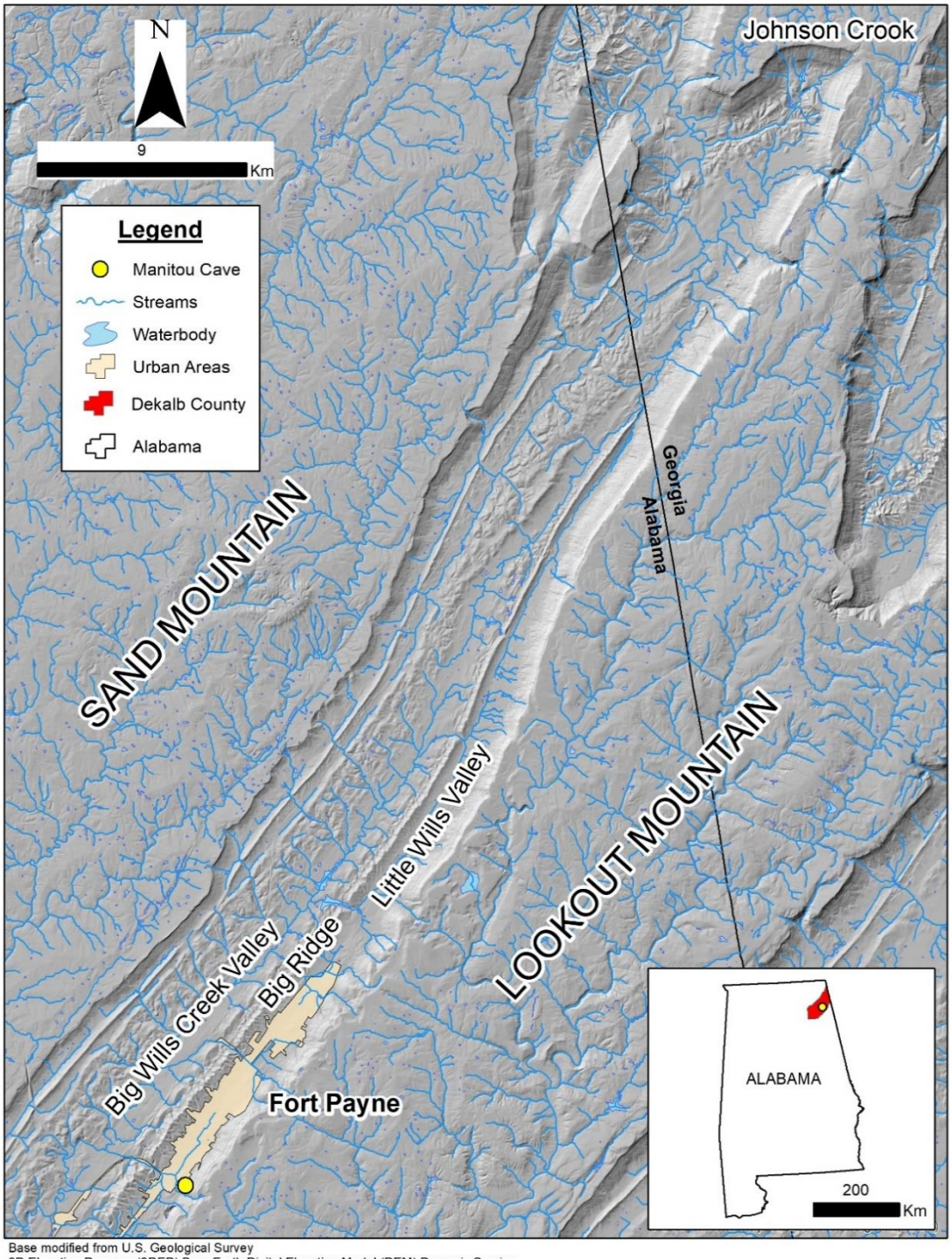
Figure 1. A Manitou Cavesnail (*Antrorbis breweri*) grazing on a stream cobble. The snail shell is approximately 2.7–3 mm diameter. (Photo taken by Alan Cressler. Used with permission.)

Service (USFWS) to federally list the snail as an endangered species (Center for Biological Diversity, 2010). However, listing a species first requires identification of potential threats to be identified. In the case of the Manitou Cavesnail, little was known about possible outside threats since the recharge area for the cave was unknown. As a result, following discussions in 2016 between state and federal agencies and nonprofit organizations, the U.S. Geological Survey initiated a dye tracing study to delineate the recharge area of the stream in Manitou Cave where the snail lives. The results from the study provided the USFWS with necessary information to begin an assessment of potential threats to the snail to inform the decision over whether and how to include *Antrorbis breweri* on the endangered species list.

Setting

The study area is located in northeastern Alabama (Fig. 2) near the town of Fort Payne on the western escarpment of Lookout Mountain. The study area is within the Cumberland Plateau physiographic region, specifically the Lookout Mountain and Wills Valley districts. Local relief is about 286 m (940 ft) from the top of Lookout Mountain at an elevation of 530 m (1740 ft) to the valley of Little Wills Valley Creek at 244 m (800 ft) (National Geodetic Vertical Datum of 1929).



Base modified from U.S. Geological Survey
3D Elevation Program (3DEP) Bare Earth Digital Elevation Model (DEM) Dynamic Service
Hillshade function from DEM (USGS, 2020)
Streams and waterbody data from U.S. Geological Survey
National Hydrographic Dataset (USGS, 2019)

Figure 2: Map showing streams, cities, and terrain within the study area as hillshade derived from Digital Elevation Model (DEM) created from light detection and ranging (lidar) data (USGS, 2019; USGS, 2020). Major features of the study area, referenced in text, are labeled. Inset shows location of Dekalb County within the state of Alabama.

Annual precipitation totals about 150 cm (60 in), with most of the rain falling in winter and early spring. During base flow, upland streams draining the western escarpment of Lookout Mountain sink into limestone of Mississippian (Carboniferous) age near the contact with overlying siliciclastic strata of Upper Mississippian through Lower Pennsylvanian (Carboniferous) age. These sinking streams feed cave streams that resurge at small springs located at the base of the escarpment, forming surface streams that flow to the northwest through water gaps in Big Ridge to Big Wills Creek and eventually to the Coosa River.

Along Lookout Mountain, the general stratigraphic sequence is similar to the Cumberland Plateau (Irvan, 2018). The strata have more structural deformation than in other parts of the Cumberland Plateau due to the Lookout Mountain syncline. West-northwest of the Lookout Mountain escarpment in the vicinity of Manitou Cave is a series of parallel ridges and valleys resulting from the Wills Valley anticline, an elongated structure that extends southwest from Johnson Crook, Georgia, to Gadsden, Alabama (not shown on map) (Fig. 2; Coleman et al., 1988).

Lookout Mountain is capped by the Pennsylvanian Pottsville Formation, a conglomeratic sandstone consisting of two main units separated by a shale interval. Below the Pottsville Formation are the dominantly siliciclastic Pennsylvanian Parkwood and Upper Mississippian Pennington Formations, which are undifferentiated in the study area. The Pennington Formation has interbeds of limestone, which in some areas of the Cumberland Plateau exhibit karst features including springs, stream sinks, and caves (Steinmann, 2018). Beneath the Pennington Formation are the Mississippian Bangor and Monteagle Limestones (undifferentiated) extending from the lower slopes of Lookout Mountain across the floor of Little Wills Valley. These limestones are medium to massively bedded, very pure, and are susceptible to extensive chemical weathering and karstification. The Hartselle Sandstone, a thin siliciclastic formation that commonly separates the Bangor Limestone from the Monteagle Limestone, is absent in the study area.

The lengths of caves in the study area are variable ranging from as short as 20 m to several kilometers. Larger caves include Steward Spring Cave (3.95 km long) (Guy, 2009b), Stanley Carden Cave (3.23 km long) (Guy, 1990), and Allen Cave (1.8 km long) (Guy, 1975). The longer caves tend to be sub-parallel to the escarpment face and typically contain active streams flowing south to north. Manitou Cave is a 1.7-km-long stream cave (Guy, 2009a) formed in the Mississippian Bangor Limestone, based upon the cave's position in the upper portion of the undifferentiated unit. Most of the cave passages are large phreatic passages with an incised, perennial meandering stream that has downcut during vadose conditions (Fig. 3). The cave was commercialized during two periods of time, first in the 1880s as a largely lantern-led tour and again in the 1950s when concrete walkways, bridges, and electrical lighting (now absent) were added. The cave is primarily known for its historical and archaeological importance. Saltpeter mining artifacts are common in the cave, along with thousands of historical signatures. Manitou Cave is one of only a handful of caves in which Cherokee syllabary has been documented to date (Carroll et al., 2019; Carroll et al., this volume).

Methods

In karstic dye tracing studies, one of the first tasks is to complete a thorough karst hydrologic inventory (KHI) to identify monitoring sites and potential injection locations. As part of the KHI

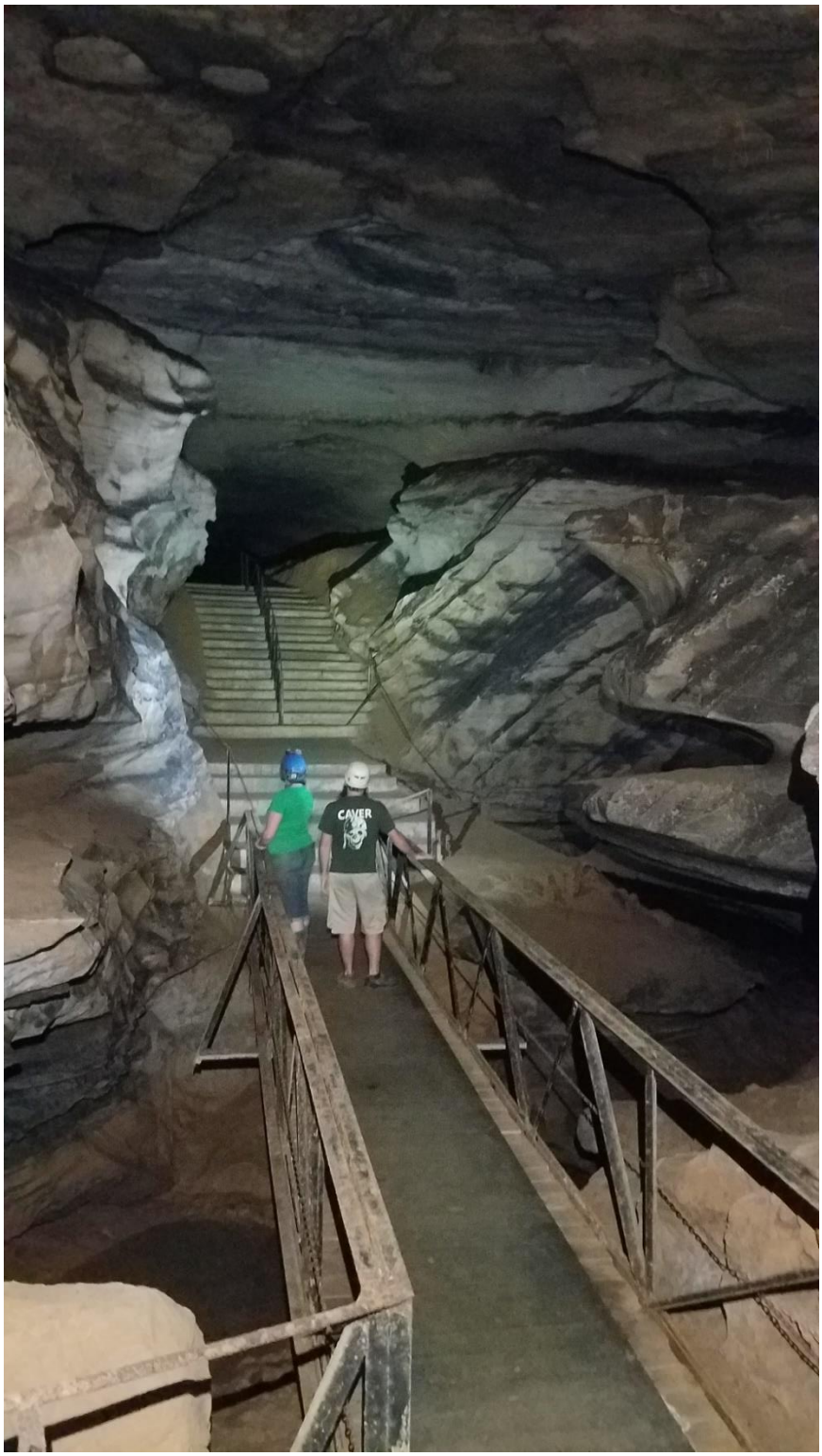


Figure 3. Photograph of interior of Manitou Cave along the historic tour route. Much of the cave consists of an upper dry phreatic passage with a lower incised vadose canyon carrying the active meandering stream. (Photo by Ben Miller, USGS)

for this study, discharge features were inventoried including springs, surface streams, cave streams, karst windows, and in some cases, wet-weather resurgences. During the KHI, charcoal packets, used for detection of the dyes, were placed in selected discharge features in order to collect initial samples of background fluorescence before any dye is injected. These background samples allow for removing any influence from naturally occurring fluorescence or anthropogenic impacts when analyzing packets post-injection. Recharge features such as sinking streams, swallets, losing streams, and sinkholes were also evaluated for use as potential dye injection locations. In the Manitou Cave area, access to multiple private properties was necessary in order to perform the KHI since the entire surrounding area is privately owned. Discussions with the private landowners provided an opportunity to learn about other possible features to monitor and to explain the ongoing study. For this study, 25 monitoring sites were identified; the locations of these sites are shown in Figure 4 and listed in Table 1.

Charcoal packets were placed at discharge features and in local streams to monitor for the presence of fluorescent dye. Packets consisted of approximately 5 g crushed coconut charcoal encased in a milk filter sock and attached to a vinyl coated wire and weights. Packets were placed directly in the flow of the feature and attached to the stream bank with the wire. Packets were changed at timed intervals that aided in determining travel time and also in several cases helped to determine if a particular storm event may have mobilized the dye. Due to the high concentration of the dyes used and the low detectability achieved in laboratory analysis, special care had to be taken in order to prevent false positives and cross contamination between sites. Thus, any time charcoal packets were placed or retrieved, care was taken to wear fresh gloves, place packets in individual labeled bags, and to stand downstream of any packet location. After packets were retrieved, selected packets were sent to Crawford Hydrology Laboratory (CHL) in Bowling Green, Kentucky, for analysis. At CHL the packets were rinsed, dried, weighed, and eluted prior to fluorometric analysis of the eluted solution using a Shimadzu© RF-5301 Spectrofluorophotometer.

Dye injections utilized common non-toxic fluorescent groundwater tracing dyes, specifically fluorescein (FL), eosine (EO), sulphorhodamine B (SRB), and rhodamine WT (RWT). These dyes have been used in thousands of groundwater traces and are easily detectable through the analysis methods used at CHL (Smart, 1988; Ryan and Meiman, 1996; Goldscheider et al., 2003; Miller et al., 2015). Recharge features for the injections were selected during the preliminary KHI. Following this selection, a round of dye injections was performed at four different locations, using a different dye at each location. If flowing water was present at a dye injection location, then the dye was poured directly into the stream. Streams did not have to be a certain size for dye injections, and even small trickles of water were enough to inject dye and provide positive traces. Where water flow was absent at the injection location, powdered dye was placed into a culvert or a tube in an intermittent streambed (referred to as a “dry set”) allowing runoff from subsequent storm events to carry the dye into the system. In this study, dye was injected at six flowing water sites and dry sets were used at two sites without stream flow. In each injection, care was taken to prevent the transport of dye away from the site. Bleach wipes, dye suits (Tyvex© coveralls), and gloves were utilized at all locations. A total of eight dye injections, split between two rounds, were conducted for the dye tracing study. The first round of four dye injections was performed in late June 2019. Monitoring was conducted after the injections until the fluorescence levels on charcoal packets at the monitoring sites had returned to the same levels detected in the initial background samples.

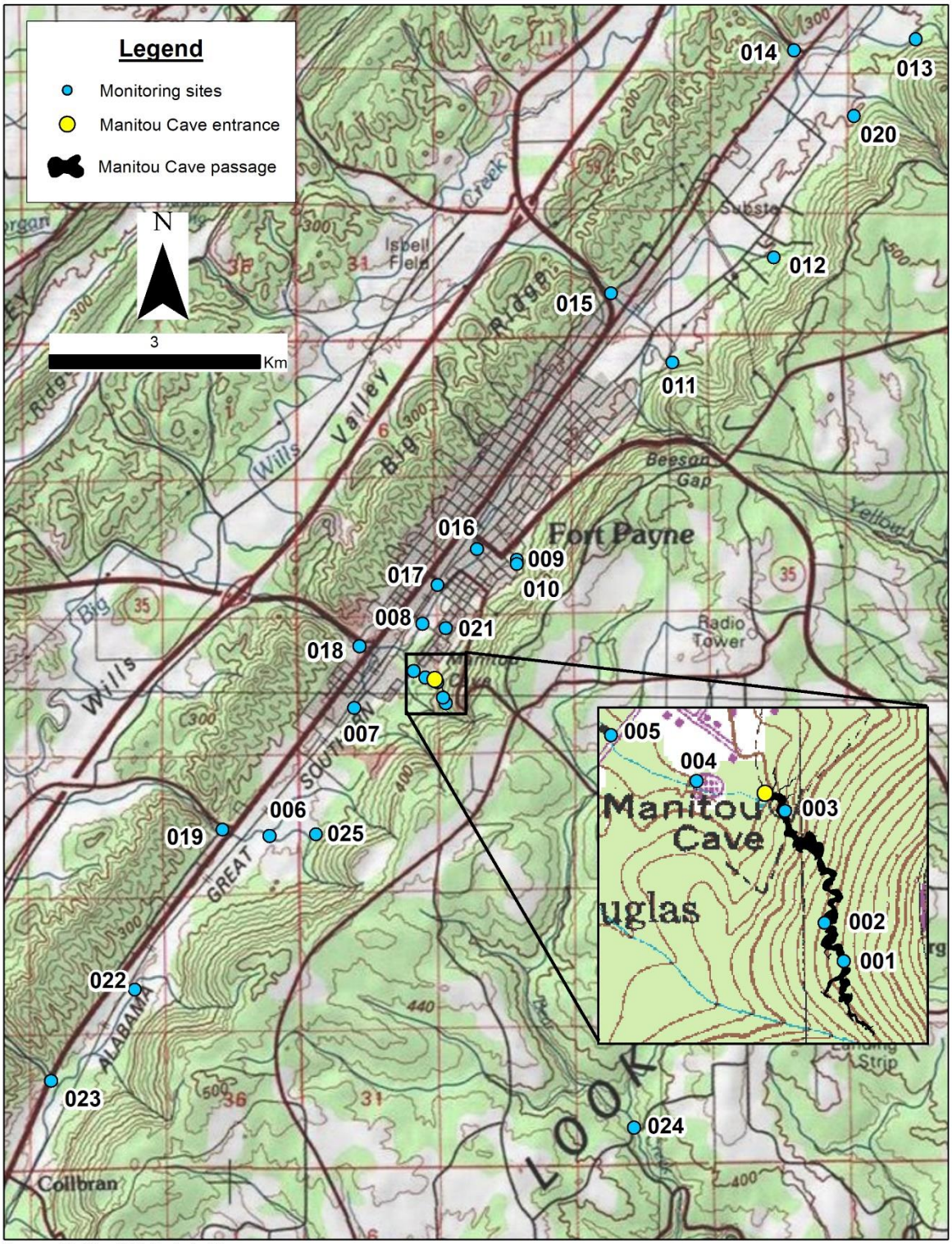


Figure 4. Map showing locations of charcoal packet monitoring points and their respective site identification numbers; site numbers correspond to Table 1.

Table 1. Charcoal packet monitoring sites. Locations are shown in Figure 4. Under site type: CV = Cave, SP = Spring, ST = Stream. All elevations were determined using National Geodetic Vertical Datum of 1929.

Site Number	Monitoring Site Name	Site Type	Elevation- m	Elevation- ft
001	Manitou Cave - upstream	CV	296.9	974
002	Manitou Cave at Dam 2	CV	293.8	964
003	Manitou Cave at Dam 1	CV	292.6	960
004	Below Manitou Cave Lake	ST	268.2	880
005	Below Manitou Cave wetland	ST	263.7	865
006	Jacoway Spring branch at Godfrey Ave. S	ST	268.2	880
007	Unnamed stream at Godfrey Ave. S	ST	268.2	880
008	Little Wills Creek at 8th St.	ST	264.0	866
009	Hawkins Dug Spring	SP	280.4	920
010	Hawkins Spring	SP	280.4	920
011	Hudgins Spring Cave	CV	289.6	950
012	Wilborn Cave Spring	CV	304.8	1,000
013	Steward Spring Cave	CV	298.7	980
014	Railroad Creek failsafe	ST	278.9	915
015	Beeson Branch at County Rd. 458	ST	275.8	905
016	Little Wills Creek upstream of Hawkins Spring	ST	272.8	895
017	Watercress Ditch Spring	SP	263.0	863
018	Little Wills Creek above Dekalb Plaza Blvd.	ST	249.9	820
019	South Little Wills Creek at Grand Ave SW	ST	265.2	870
020	Silver Cave Spring	SP	292.6	960
021	Spring Grove Spring	SP	272.8	895
022	Little Wills Valley Creek at 41st St. SE	ST	259.1	850
023	Little Wills Valley Creek at Colbran Gap	ST	243.8	800
024	Bear Creek at County Rd. 270	ST	347.5	1,140
025	Jacoway Spring	SP	274.3	900

Once background levels had been reached, a second round of four dye injections were performed in September 2019 to complement and build on the knowledge gained from the first round. After packets were analyzed, positive traces were identified and used to map karst groundwater flow from the injection location to the monitoring sites.

Results and Discussion

The results of the two rounds of dye injections are summarized below. Injection numbers, shown in parenthesis, correspond to Table 2 and are labeled on Figure 5. Dye injection locations and positive traces are shown in Table 2 and in Figure 5.

Round 1 of dye injections

Culvert at Tower Drive East and Scenic Road East (I 1)

This injection site was selected because the area showed signs of significant storm flow, and the lack of an established channel below the culvert indicated flow was sinking into the subsurface. A small seep was observed uphill from the culvert on the injection date but was dry on following visits. After several storm events, the site was visited and all powdered dye had been flushed from the culvert.

Eosine was detected via charcoal packets at Hudgins Spring Cave between July 24 and September 5, 2019. The concentration on the retrieved packets (27 ppb) was similar to other positive traces in the area. This trace indicated that the recharge area for Hudgins Spring Cave may be one of the larger in the study area extending south of Beeson Gap along the escarpment of Lookout Mountain.

Unnamed stream at Rosewood Drive (I 2)

Fluorescein was injected at an unnamed stream at Rosewood Drive on June 14, 2019, and appeared at Hawkins Spring between June 28 and July 2, indicating a travel time ranging from 3 to 7 days. The trace was visually confirmed on both July 2 and July 9, when dye was still visible (and the concentration on retrieved packets was 25 ppb). Because of the high concentrations still present (i.e., still visible) on July 2, the packet was not retrieved in order to prevent cross contamination with other sites. Fluorescein was present in the system through September though at much lower concentrations.

Beeson Gap Creek at Beeson Gap Road NE (I 3)

Beeson Gap Creek is located high on the escarpment, yet there was minor eutrophication and oligochaetes (segmented worms) observed in the field, indicating some source of nutrient enrichment upstream.

Sulphorhodamine B appeared at Hudgins Spring Cave before June 28, 2019, indicating the dye took less than 3 days to travel from Beeson Gap Creek to the spring. The dye was still visible, though noticeably fainter, on July 2 and barely visible on July 9.

Unnamed stream below "Fort Payne Gap Lake" (I 4)

Rhodamine WT was injected at an unnamed stream downstream from a small lake located west and downslope from Fort Payne Gap on June 28, 2019. On the date of the injection and on several subsequent visits to the site, no visible streamflow was observed downstream from the injection site at the base of the mountain. This lack of streamflow indicated subterranean piracy of the streamflow downstream from the injection site.

Table 2. Table of dye injections and positive traces conducted during the Manitou Cave study. Dye injection and positive traces are shown in Figure 5. All elevations were determined using National Geodetic Vertical Datum of 1929.

Injection Number	Elevation - m (ft)	Strata	Flowing Water Present	Dye injected (amount)	Date injected	Recovery Site Name	Elevation - m (ft)	Strata	Date Recovered	Elutant dye concentration - ppb
I 1	517 (1,696)	Pottsville Fm.	No	Eosine (1.8 kg)	6/14/2019	Hudgins Spring Cave	287 (940)	Bangor-Monteagle	9/5/2019	27
I 2	415 (1,360)	Parkwood-Pennington Fm.	Yes	Fluorescein (0.9 kg)	6/25/2019	Hawkins Spring	280 (920)	Bangor-Monteagle	7/2/2019	25
I 3	409 (1,340)	Parkwood-Pennington Fm.	Yes	Sulphorhodamine B (1.8 kg)	6/25/2019	Hudgins Spring Cave	287 (940)	Bangor-Monteagle	7/2/2019	2350
I 4	421 (1,380)	Parkwood-Pennington Fm.	Yes	Rhodamine WT (0.45 kg)	6/28/2019	Manitou Cave	283 (930)	Bangor-Monteagle	7/2/2019	21
I 5	403 (1,320)	Parkwood-Pennington Fm.	Yes	Rhodamine WT (0.68 kg)	9/6/2019	Manitou Cave	283 (930)	Bangor-Monteagle	11/15/2019	13
I 6	393 (1,290)	Parkwood-Pennington Fm.	Yes	Eosine (0.9 kg)	9/6/2019	Jacoway Spring	274 (900)	Bangor-Monteagle	10/4/2019	>1,400
I 7	366 (1,200)	Parkwood-Pennington Fm.	No	Sulphorhodamine B (0.9 kg)	9/6/2019	Jacoway Spring	274 (900)	Bangor-Monteagle	11/15/2019	36
I 8	438 (1,437)	Pottsville Fm.	Yes	Fluorescein (0.9 kg)	9/6/2019	Bear Creek failsafe	341 (1,120)	Pottsville Fm.	11/15/2019	1

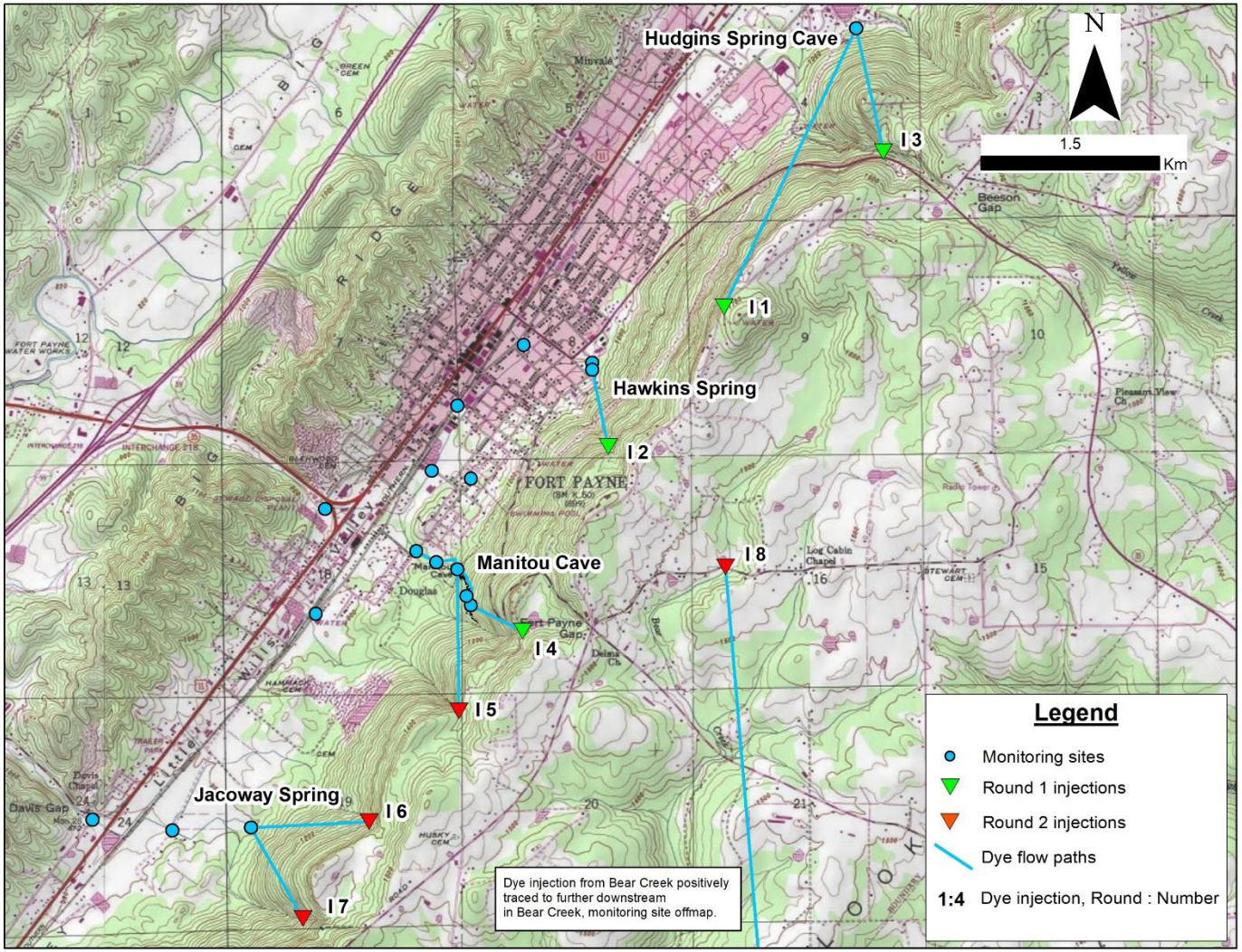


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Figure 5. Map showing the positive traces from injection points to monitored locations. Dye injections are labeled with the injection numbers found in Table 2; positive traces are also summarized in Table 2.

Rhodamine WT was detected at multiple sites in Manitou Cave beginning on July 2, 2019 (3 days, 21 hours travel time) and was detected through late July. Detection of the dye in Manitou Cave was the first positive trace to the cave and provided insight into the area impacting the cave stream and snail habitat.

Round 2 of dye injections

Unnamed stream near Vulcan Quarry (I 5)

Rhodamine WT was injected into a small (2 m x 2 m) shallow pool in a bedrock streambed just above the edge of the escarpment. The streambed was dry upstream and downstream of the pool.

Rhodamine WT was detected in eluted solution from charcoal packets retrieved from two in-cave sites at Manitou Cave on November 15, 2019, at the upstream (Site 001) and Dam 1 (Site 003) locations (Table 1). According to weather data provided by the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS), over 22.5 cm of precipitation fell in the Fort Payne vicinity between charcoal packet retrievals in October and November, with multiple events exceeding 5.7 cm/day (CoCoRaHs, 2019). Because of non-detects on charcoal packets retrieved prior to November 15, it is believed that storm events mobilized the dye near the end of October and beginning of November. The dye concentration in eluted solution from Site 003 (Dam 1) was approximately 10 times greater than that from the upstream location at Site 001, suggesting the possibility of a hidden, otherwise unknown tributary between the two recovery sites with a larger flow contribution from the unnamed stream to which dye was introduced. This trace represented the second positive trace to Manitou Cave and extended the recharge area to the south-southwest.

Unnamed stream with small seep west of Husky Cemetery (I 6)

A small seep was located along the left edge of the ravine (looking downstream) of an unnamed stream and the resulting flow was observed to be sinking into the streambed approximately 3 m downslope of the seep. By digging out some organic debris and small cobbles, a pool was formed allowing for injection of eosine dye.

Eosine was detected at Jacoway Spring at very low concentrations (<1 ppb) from packets retrieved on October 4, 2019. Subsequently, eosine was detected in extremely high concentrations (>1,400 ppb) in the packets retrieved on November 15, 2019. It is believed that water from the small seep flowed to the spring, resulting in the initial low concentration detection. However, the large amount of rainfall in October and November likely flushed the bulk of the dye through the system. This trace helped to define the southern boundary of the Manitou Cave recharge area.

Unnamed stream southwest of Stephens Field (I 7)

The sulphorhodamine B injection was conducted in a very steep ravine of an unnamed wet weather stream filled with large sandstone boulders. The streambed was traversed from the edge of the escarpment down to an elevation of 323 m (1,060 ft) and no flowing water was encountered. Because of the lack of streamflow, a dry set was placed at the site on September 6, 2019.

Sulphorhodamine B was detected in high concentrations at Jacoway Spring in the packets retrieved on November 15, 2019. There was no detection of the dye at the site prior to

November 15, thus it is likely the rainfall events in October and November created enough surface flow to inject the powdered dye in the dry set.

Bear Creek at Fruit Farm Road East (I 8)

Fluorescein was injected in the upper reaches of Bear Creek on September 6, 2019. Because the site was located on top of Lookout Mountain and within siliciclastic strata, there was a strong possibility the dye would remain in the stream channel. However, a charcoal packet located approximately 6.4 km downstream from the injection site received a minor detection of fluorescein (<1 ppb). It is believed that the movement of the dye may have been slowed by a lake located 2.9 km downstream from the injection location and could have led to degradation of the dye as a result of photolysis by sunlight.

Manitou Cave Recharge Area

Using the dye tracing results from the two positive traces to Manitou Cave, and positive traces to other adjacent springs, an overall recharge area of 1.22 km^2 (0.47 mi^2) was delineated for Manitou Cave (Fig. 6). Included within the recharge area is a 0.07-km^2 epikarstic recharge area, which is estimated based on a 75-m buffer extending out from the centerline of the cave passage The epikarstic recharge area would be the source of water to dripping domes, speleothems, and other seepage in Manitou Cave. The boundary of the overall recharge area (Fig. 6) is a combination of a “defined” boundary and an “interpreted” boundary. The defined boundary is an area composed of sandstones and shales that provide allogenic recharge to the limestone units located downslope. In these areas, there is little chance that water might sink and flow out of the topographic-defined drainages, due to the insoluble nature of the strata and lack of karstification. The lower elevations of the overall recharge area are bordered by an interpreted boundary where the underlying strata is limestone and karstified. In these areas, streamflow sinks into the subsurface and contributes autogenic recharge to the cave stream. The interpreted boundary merges with the epikarstic recharge area near the downstream end of the cave system and indicates potential recharge areas that are downslope of the more geologically and topographically constrained areas.

In terms of land use as reflected by land cover, the majority of the recharge area (>70%) is covered by deciduous forests (Fig. 7) (Yang et al., 2018). The next highest land use is developed open space, which is approximately 10% of the recharge area and largely consists of lawn space around residences. The remaining land uses include hay/pasture (~6%) and mixed forest (~5%), with all other land uses comprising less than 2% of the total area. Currently, there is no high-intensity developed land in the recharge area; developed land, including open space, comprises only 12.3% of the total recharge area.

Potential sources affecting water quality/quantity at Manitou Cave

Delineation of the recharge area for Manitou Cave helped identify various types of land uses that could pose risks to water quality and quantity in the study area. The 1.22-km^2 recharge area includes more than 29 residential homes and 4.65 km (2.9 mi) of paved roads (Fig. 7).

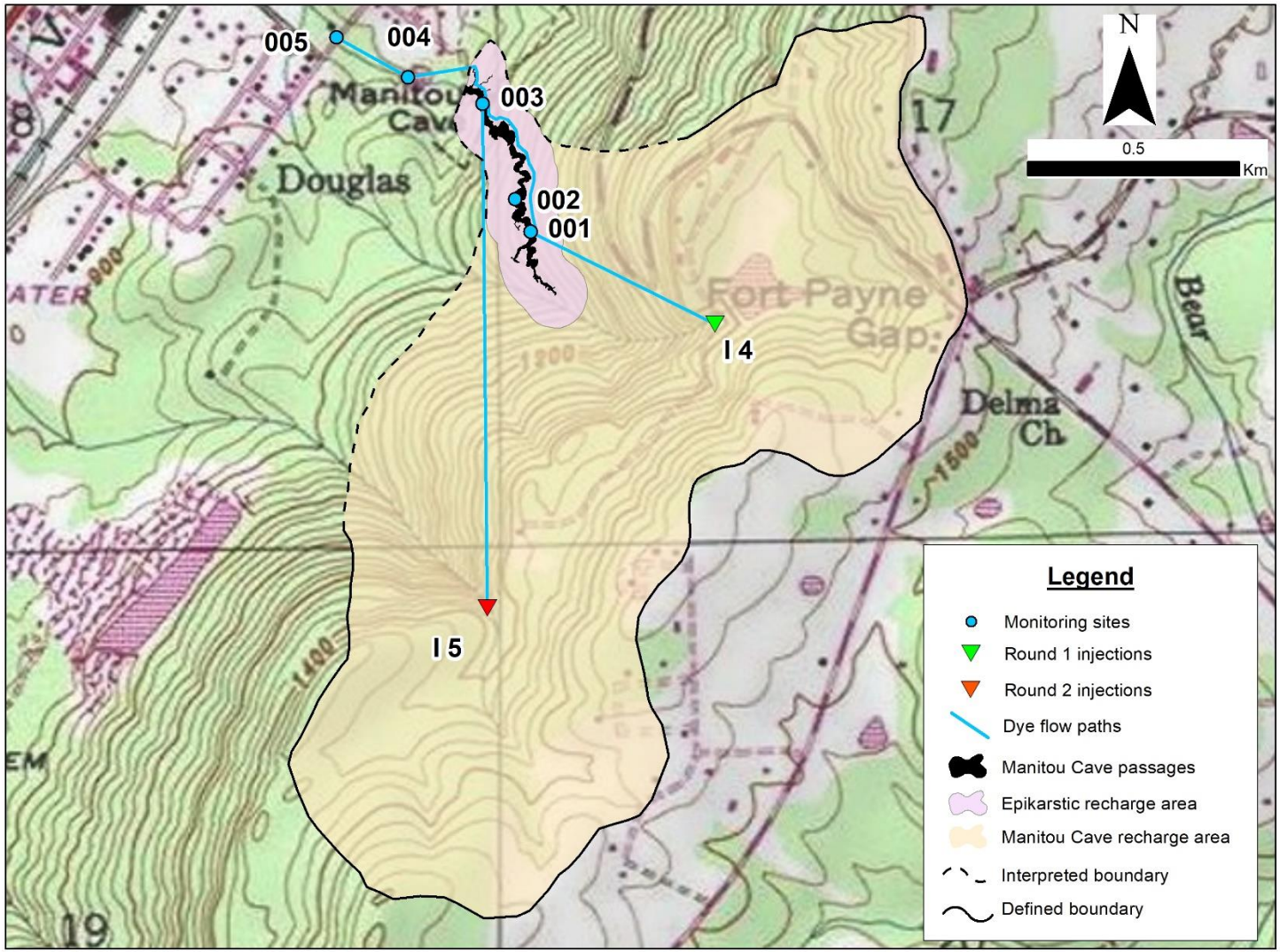

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Figure 6. Recharge area for Manitou Cave showing positive traces used to delineate the area. Numbers on injections correspond to Table 2 and the monitoring sites numbers correspond to Table 1.

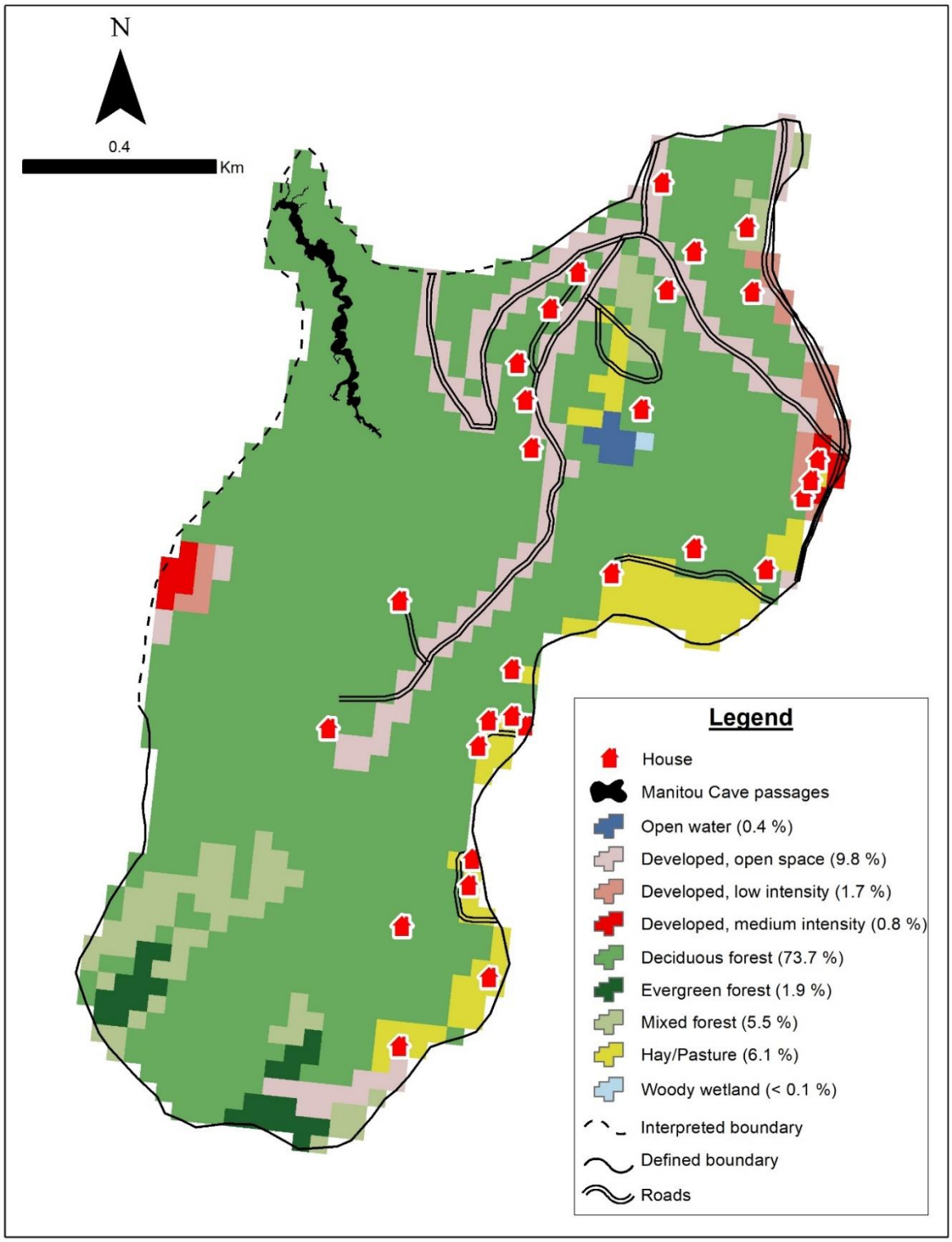

Figure 7: Land use/land cover data for the Manitou Cave recharge area. Also shown are the locations of houses and roads within the recharge area. Land use/land cover data from National Land Cover Database (Homer et al., 2016).

Residential communities can pose risks to sensitive aquatic biota from a variety of sources including fertilizers, pesticides, septic tanks, impervious surfaces, pet feces, and siltation. For example, residential lawns commonly receive higher applications of fertilizers than agricultural lands and the phosphorus contained in many fertilizers can cause eutrophication and low oxygen conditions, which can impact aquatic species (Morton and others, 1988; Nielson and Smith, 2005). Likewise, impervious surfaces found within residential communities can increase the potential for runoff to local streams, which may contain petrochemicals (from oil or gas leaks), surfactants (from washing cars), and other potential contaminants.

Roadways passing through or bordering the recharge area can affect water quality and quantity in the study area in a variety of ways. For example, County Road 78/Adamsburg Road East is a main highway that makes a sharp switchback through the recharge area along a steep part of Lookout Mountain. Vehicular accidents occurring along the road pose a risk to the cave stream water quality from fuel, oil, or other hazardous liquids that may be spilled at the time of an accident. Many trucks use the road including tanker trucks that carry a variety of different materials and liquids, which could be toxic to aquatic biota should a spill occur. Additionally, many road-maintenance crews use oil coatings on asphalt roads as a means of sealing cracks, and these coatings have the potential to migrate to streams through runoff. Also, roadside vegetation is commonly sprayed with herbicides to reduce their growth into the roadway. While these applications pose a low risk if done at the right time and application rate, a rain event following a recent application could transport these chemicals to losing streams via runoff.

Other potential point and non-point sources of contamination that border the recharge area include gas stations, row crop agriculture, and a nearby quarry. Gas stations increase the potential for a fuel release through transfers to tanks, leaky storage tanks, and/or spillage by customers. Fertilizers, pesticides, and herbicides are often used to increase crop yields, and soil tillage can result in sedimentation, which has been shown to cause declines in other stygobiont snail populations (Neill and others, 2004; Elliott and Aley, 2006; and Elliott and others, 2008). A nearby quarry appears to be a lower risk to water quantity than previously thought. The quarry contains an inactive underground (overhead) quarry and a lower valley floor open pit, which is actively mined and occasionally dewatered. The water removed from the open pit, however, is pumped into the underground portion of the quarry where it is stored and used as needed. This water in storage may be preventing drawdown of the local water table, which could negatively impact water quantity in Manitou Cave; however, it is recognized that this is a current condition and may not reflect all future use.

Finally, there are a small number of legacy issues related to Manitou Cave itself. During the commercialization of Manitou Cave, a series of low concrete dams were built to create ponded portions of the stream. The intended purpose of these dams, whether for scenic value or to possibly make the cave stream appear larger, is unknown. Regardless, these dams have created substantial sediment deposits, which extend upstream for an appreciable distance (150+ m) from the dams. This fine-grained sediment is likely decreasing potential snail habitat and the dams prevent the removal of the sediment, which is deposited following precipitation events. The impoundment of the stream also creates low oxygen conditions, due to the absence of riffles and other features that allow oxygen to be dissolved into the stream water. Additionally, there are a number of old timbers and lumber located in a few different areas of the cave, which are remnants of past tour paths. Many of these timber and lumber pieces are treated lumber, which historically contained toxins harmful to biota including creosote; pentachlorophenol; and chromated arsenicals, which contain copper, chromium, and arsenic (Maas and others, 2002;

Townsend and others, 2005; and Vance and Jacobs, 2005). These internal legacy issues can likely be mitigated but will require consultation with biologists and cultural resource specialists to minimize potential harm to the snail due to changing conditions.

Summary

Manitou Cave in northeastern Alabama is the only known habitat for the Manitou Cavesnail (*Antrorbis breweri*). Following a petition to federally list the Manitou Cavesnail as an endangered species, the USFWS initiated an assessment of the potential threats to the health and status of the stygobiontic snail. Due to the interconnected nature of karst and the influence of surface activities on water quality, the need for a delineated recharge area for the cave was necessary. As a result, from June to November 2019, the USGS conducted a series of eight dye injections near Fort Payne, Alabama, to delineate a 1.22-km^2 recharge area for Manitou Cave. Delineation of the recharge area enabled further identification of possible point and non-point sources of contamination that could pose risks to water quality and quantity in the recharge area and hence, the snail habitat.

Currently, land use-land cover in the recharge area is composed of over 70% deciduous forest with less than 13% of the area designated as developed land. Within the recharge area are at least 29 residences and more than 4.5 km of paved roads and county highways, which could affect the water quality and quantity within Manitou Cave. Other potential point and non-point sources of contamination exist directly adjacent to the recharge area and include gas stations, agricultural row crops, and a nearby quarry. Several legacy issues related to the cave exist from historic alterations and previous commercialization activities. The results from this study are being used by the USFWS as part of its assessment of potential threats to the Manitou Cavesnail in northeastern Alabama.

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COMPREHENSIVE BIODIVERSITY INVENTORY OF THE FERN CAVE SYSTEM AT FERN CAVE NATIONAL WILDLIFE REFUGE, JACKSON COUNTY, ALABAMA

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The 199-acre Fern Cave National Wildlife Refuge (NWR) is part of the Wheeler NWR Complex and is located in the Paint Rock River valley in western Jackson County, Alabama. Fern Cave is the largest cave system (>15 miles) in Alabama and is the largest known hibernaculum for the federally-endangered Gray Bat (*Myotis grisescens*). Although records exist for several additional vertebrate and invertebrate species, there has never been a comprehensive biological inventory conducted of the Fern Cave system. We began a two-year bioinventory study of the cave system in June 2018, implemented by the Inventory & Management Branch of the U.S. Fish & Wildlife Service, to better understand the Fern Cave system and its fauna. To date, 20 biologists and cavers have cooperatively conducted five biological survey trips (2018: June, August, December; 2019: February, July) to Fern Cave NWR covering a majority of cave passages. We have documented over 80 morphospecies in 5 phyla, 15 classes, and 33 orders, including 73 terrestrial and 11 aquatic species. At least 24 species are cave-obligates (troglobionts and stygobionts), and two and four species are federally-listed and state-priority species, respectively. Significant observations include Torode's Cave Pseudoscorpion (*Tyrannochthonius torodei*), an undescribed cave millipede, and the discovery of a new population of the federally endangered Alabama Cave Shrimp (*Palaemonias alabamae*). Fern Cave is now tied with Shelta Cave for having the highest number of cave obligate species in TAG.

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USING ENVIRONMENTAL DNA FOR THE DETECTION AND MONITORING OF GROUNDWATER LIFE: A CASE STUDY ON CAVE-DWELLING DECAPODS IN NORTHERN ALABAMA

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Despite the importance of aquifers to humans, our knowledge of groundwater biodiversity remains limited, as subterranean habitats are particularly challenging to access and study. Most of the >450 described stygobionts in the United States and Canada have highly restricted distributions, and, consequently, are of conservation concern and at an elevated risk of extinction. The analysis of environmental DNA (eDNA) from water samples collected from springs, caves, or wells offers an exciting and potentially effective way to detect and monitor groundwater biodiversity that might otherwise be difficult or impossible to survey using traditional approaches. eDNA is an increasingly common method of monitoring biodiversity, including threatened and endangered species, that does not require actual capture of the organism but rather relies on detecting the organism's DNA in its environment. Here we discuss the development, implementation, and performance of eDNA as a tool for detection and monitoring of groundwater taxa. We highlight recent studies on groundwater crustaceans in northern Alabama, including the Alabama Cave Shrimp (*Palaemonias alabamae*), a federally endangered species known from just five cave systems, and two cave crayfishes of state conservation concern: Sweet Home Alabama Cave Crayfish (*Cambarus speleocoopi*) and Lacon Exit Cave Crayfish (*C. laconensis*). eDNA can provide a foundation for future studies complementary to traditional survey approaches to gather vital insights into the distributions of rare and threatened groundwater organisms and better inform conservation and management decisions.

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PRELIMINARY ANALYSIS OF BIOMONITORING AND CLIMATE DATA FROM 13 YEARS OF SURVEYS IN LEHMAN CAVES, GREAT BASIN NATIONAL PARK, NEVADA

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Abstract

Over the past 13 years, 14 paired stations in Lehman Caves were monitored to quantify cave invertebrate diversity and abundance. Supplementary data on cave microclimate, bait predation, and water presence were also recorded. Throughout this time period, more than 50 trips have resulted in observations of over 3,550 individuals. By field identifiable groups, the most predominant invertebrates observed were grey springtails (n=1,821), white springtails (n=1,040), millipedes (n=121), and pseudoscorpions (n=94). A marked decrease in the total number of individuals observed occurred from year 1 (n=702) to year 13 (n=94), although the downward trend has slowed, perhaps due to a change in baiting practices. Microclimate data encompassed several variables, with soil temperature appearing to be the most stable. Bait was found missing at some stations, thought to be due to rodent predation. Water presence was perennial at some cave locations, ephemeral at others, and tied to the rate of snowmelt and overall precipitation. Our survey is one of the longest-running biomonitoring efforts in a show cave.

Introduction

Lehman Caves is a show cave in eastern Nevada that has been open to the public since 1885. The cave was under private ownership until 1922, when the cave became a National Monument and transferred to the U.S. Forest Service. In 1933, management changed to the National Park Service. The Monument was subsumed into Great Basin National Park, when it was created in 1986. About 33,000 people tour the cave each year on a 1-km-long paved tour route.

Great Basin National Park is located in the South Snake Range in east-central Nevada. Lehman Caves is located at approximately 2,090 m (6,850 feet) elevation within a large fault block of Pole Canyon Limestone, which, in this location, has metamorphosed into marble. The length of the cave is approximately 3 km. The cave is known for being highly decorated, including numerous cave shields.

A cave bioinventory of eight park caves was completed in 2003 by Dr. Steve Taylor from Illinois Natural History Survey, Dr. Jean Krejca from Zara Environmental, and Mike Slay from The Nature Conservancy (Krejca et al. 2003). Based on the first surveys, a second project was funded in 2006 and 2007 and implemented by Taylor, Krejca, and Slay in 19 park caves, this time including Lehman Caves (Taylor et al. 2008). Part of the second project was to develop and implement a quantitative biomonitoring study of Lehman Caves. Fourteen paired sampling locations were selected in Lehman Caves (Fig. 1). This sampling design was chosen to determine if human impacts from recreational use (proximity to cave tour route), seasonality, and climate variables had an effect on the abundance and diversity of cave biota.

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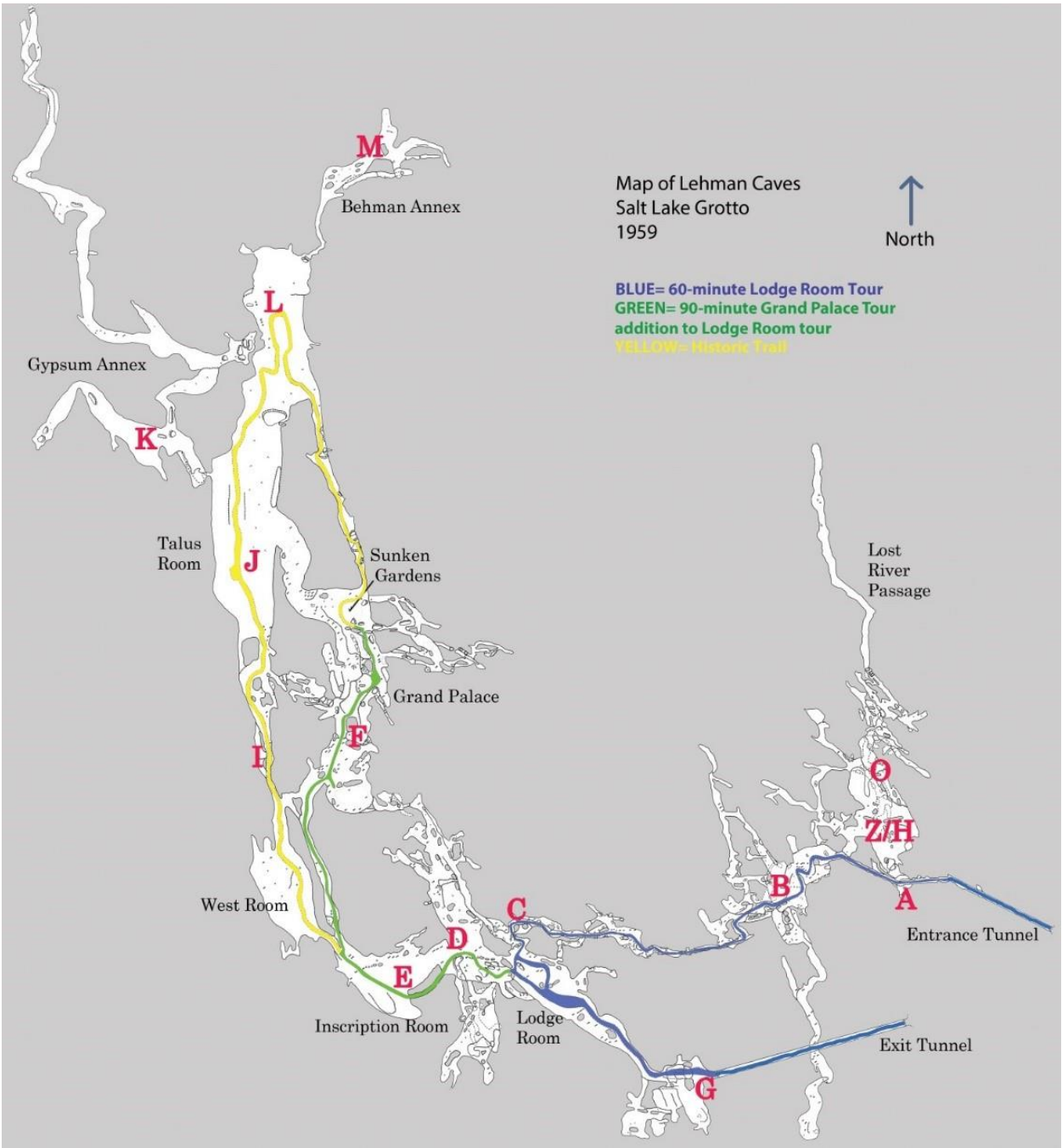

Figure 1. Map of Lehman Caves by Salt Lake Grotto. Station locations are shown with capital letters. Route in blue shows the path of the 60 minute (Lodge Room) cave tour and is considered to be high intensity visitation. The route in green is the extension for the 90 minute (Grand Palace) cave tour and is considered to be medium intensity visitation. The area in yellow is the discontinued and restored tour route through the Talus Room that was used for approximately 20 years and is considered to be low intensity visitation. The area not highlighted (locations K and M) is off-trail and considered to be no visitation.

Methods

The fourteen paired survey locations were installed in Lehman Caves in 2006. Each of the paired survey locations had a near-trail (e.g. Station A) and a far-from-trail bait station (e.g. Station AA, Fig. 1). For the first year (July 2006–June 2007), stations were baited and surveys were conducted monthly. Starting July 2007, survey frequency decreased to quarterly (January, April, July, and October). Only quarterly visits are included in the results. Each station was baited on day 1 with a small amount of bait (approximately 2 cm by 2 cm placed on the underside of a rock). Twenty-four hours later, on day 2, a 1-meter-diameter area around each bait station was surveyed for cave biota. Bait was removed during the day 2 survey. Search effort was recorded for each bait station (minutes searched). When cave biota was observed, we recorded field identifiable group, number of individuals, microhabitat information, and proximity to bait. Microhabitat data included location (on or under), surface moisture (dry, wet, or normal) and surface type (rock, soil, or formation).

Changes to bait type and bait placement were made once surveys were underway. Limburger cheese was used as bait in year 1 (July 2006–April 2007). We started using rancid peanut butter as bait in July 2007 (year 2) because of difficulty purchasing the cheese bait. Our placement of bait changed in October 2009 (year 4). Instead of placing peanut butter directly on a rock, bait was placed on a small piece of flagging and then placed under a rock at each bait station. We found that putting bait directly on rocks and the difficulty in removing all the bait from the rock served as a potential food source and a medium for fungal growth.

In 2009, Stations K and KK in the Gypsum Annex were abandoned due to a lack of observations, difficult access, and fragile cave formations. In April 2012, Stations H and HH were replaced with new Stations Z and ZZ, located about 30 m from the original H and HH sites to protect cultural resources.

Microclimate data including air temperature, soil temperature, relative humidity, wet bulb, and dry bulb were recorded at the near-trail station (A). Microclimate data were collected using a Novus Series RT Digital Pocket Thermometer and an Extech Precision Psychrometer RH390. If water was present near the bait stations, we collected basic water quality data—water temperature, pH, and specific conductance using a handheld, multi-parameter meter (YSI for 2006–2014, and Oakton for 2014–2019).

Results

A total of 3,550 individual observations were made over the 13-year survey period (2006–2019) and 50 survey trips. The most frequently encountered identifiable groups (assigned common name designations for field use) were grey springtails (n=1,686), white springtails (n=993), millipedes (n=114), and pseudoscorpions (n=92). Other field identifiable groups observed included beetles, flies, spiders, moths, and bats.

There was a general downward trend in the number of observations in the first 5 years (Fig. 2). This decline was followed by annual variation in the number of observations from year 5 to year 13.

Biomonitoring included one visit per season for 13 years. We found the greatest percentage, 33 %, of cave biota in autumn (October) and the least amount of cave biota in summer (July), with 17 % of the total (Fig. 3).

Moisture levels seemed to play some role on cave biota presence. Generally, all groups of cave biota were found in “normal” moisture conditions (Fig. 4). Pseudoscorpions (Fig. 5) were never found in wet moisture conditions. Temperature did not seem to be a factor for presence of cave biota.

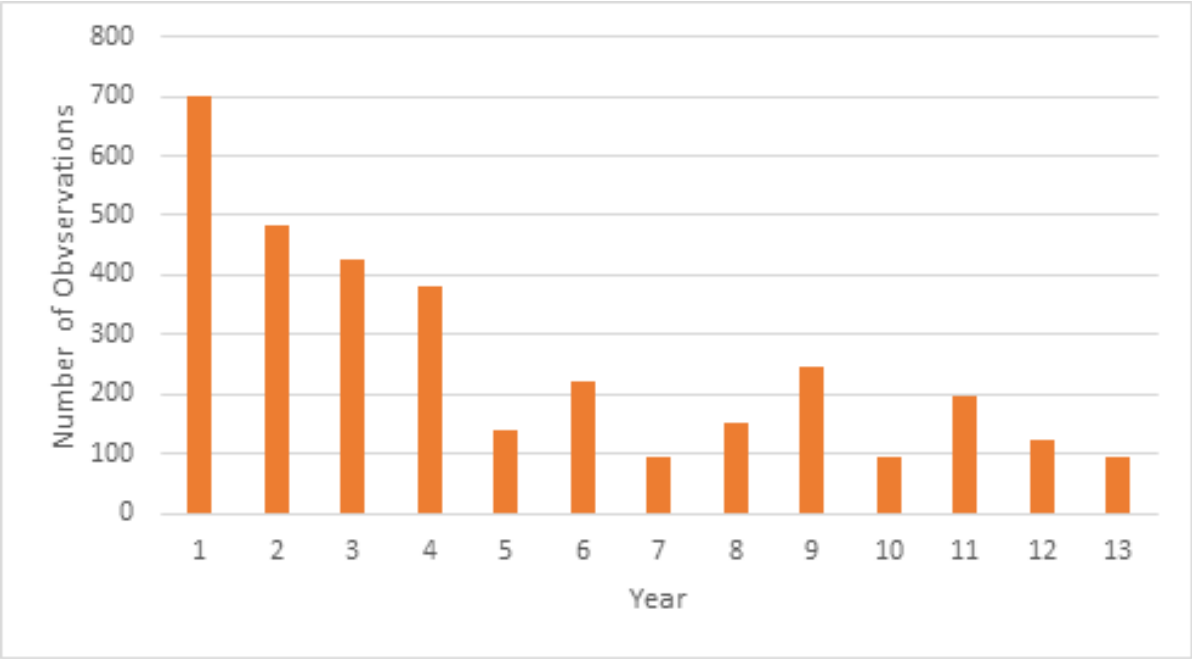

Figure 2. Annual total abundance (number of total observations) of cave biota from quarterly biomonitoring in Lehman Caves, Great Basin National Park, Nevada (July 2006–April 2018).

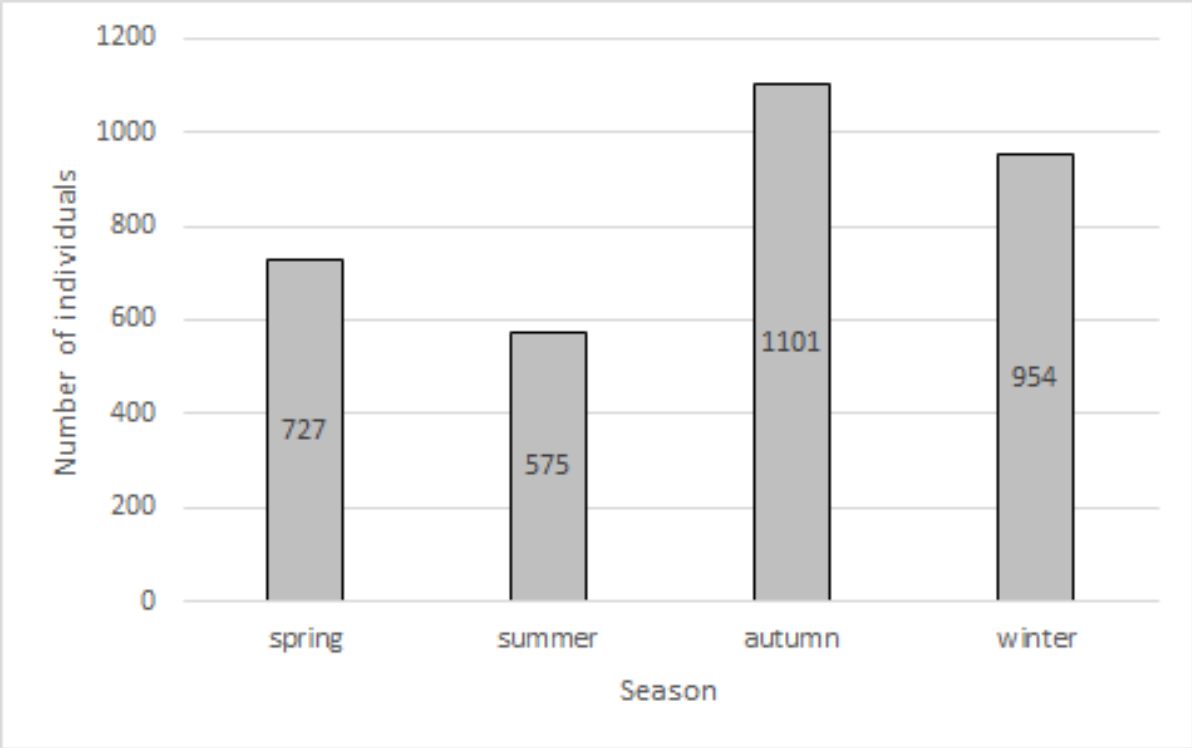

Figure 3. Number of cave biota observations for each sampling season (Spring/April, Summer/July, Autumn/October, and Winter/January) in Lehman Caves, Great Basin National Park, Nevada.

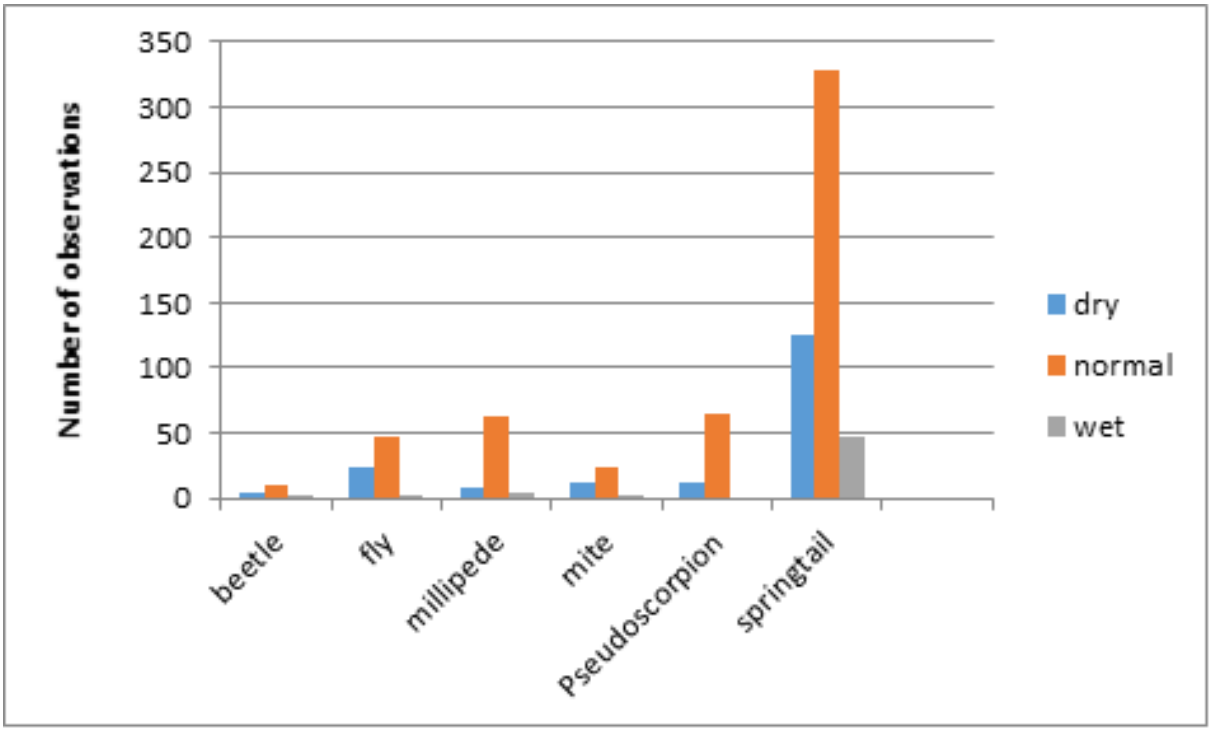

Figure 4. Moisture conditions and abundance of most common cave biota during cave biomonitoring in Lehman Caves, Great Basin National Park, Nevada.

Figure 5. Lehman Cave pseudoscorpion, *Microcreagris grandis*.

Microclimate data gathered over the 13-year survey showed that soil temperature was the most stable parameter measured. The average soil temperature for all sites was 11.05 °C, with a maximum of 11.9 °C and a minimum of 9.45 °C.

The bait was missing 67 times, always near the entrance. We attributed this to rodents, primarily mice, which we occasionally saw alive or dead during the biomonitoring.

While we saw some species frequently, like springtails, some species were extremely rare. We did not find a dipluran until the 9th quarterly visit, in year 3, and have only seen one other since then. A lizard was found on the 14th quarterly visit, in year 4.

Water presence in the cave varied.

Discussion

Changes in baiting practices appear to account for the large drop in number of cave biota observations over the years, particularly years 1 to 4. During that time, it was not uncommon to find 200 springtails at a site, gorging on the tiny bit of bait that had accidentally been left behind. With improved baiting practices starting in year 4, the number of observations is steadier and appears almost cyclical.

We do not know why it took so long to find a dipluran, seen in year 5 and once again in year 6, but on no other trips. Are diplurans so rare that they are seldom seen? Or are they just so hard to detect that we are not seeing them? More work needs to be done looking at occupancy rates and detection, as well as research on dipluran natural history in caves. We have been unable to identify any experts on cave dipluran ecology working in the United States, making this difficult.

Limited sampling, just four times a year, means that it will take a long time to make inferences. If we do not see a pseudoscorpion on two consecutive visits, is that something of management concern? Probably not, but what if we don't see one on four consecutive visits? Further data and the statistical analysis it would support are needed.

Although our statistical analyses are limited at this time, we are undertaking a more rigorous paper to develop those. At this time, we can report some summary statistics. We also can report on side benefits of doing this project. Four times a year we have permanent park employees entering the cave and seeing the same route each time. These employees can monitor overall cave health, such as if there are problems in the cave lighting system, excessive lint or lampenflora, and increased amount of water in pools. In addition, new park staff and volunteers are taken into the cave on the biomonitoring trips, allowing for increased awareness of park resources, which results in additional interpretation and education about cave biota.

Finally, this is one of the longest-running biomonitoring efforts in a show cave.

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- Over 50 volunteers from park staff, grottos, interested public
- Initial funding from NPS
- Steve Taylor, Jean Krejca, and Mike Slay helped set up this study.

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TREE ROOTS IN CAVES OF QUINTANA ROO, MEXICO: ECOLOGICAL INSIGHTS AND CONSERVATION IMPLICATIONS

Rachel E. Adams[1c], Thomas M. Iliffe[2], Jason B. West[1]

While ecological connections between the surface and subterranean realms are inherent, the two are sometimes set apart and not studied collectively. In the Yucatán Peninsula of Mexico, tree roots link these two worlds, making them impossible to separate. Here, roots commonly grow into caves, often contacting groundwater. Yet, little is known about which tree species provide these roots or how the tropical forests and caves are associated ecologically. To investigate this, we established paired above and below ground plots at five private caves in Quintana Roo. We evaluated relationships between forest composition, water access, and root biodiversity through biomass surveys, stable isotopes, and genetic approaches. Results show that nearly half of the tree species present above ground were found in caves. Root biodiversity in caves was dominated by the families Moraceae and Fabaceae, and species from these families were the dominant species above ground as well. Stable isotopes from stem water showed increased cave water use with increasing tree size, which corresponded to a decrease in water stress. Local bedrock characteristics contributed to observed variability in water access within the karst landscape. This work demonstrates that multiple tree species have potential to access water in caves, but access seems limited by the bedrock itself. During field work, interest in the tree roots among landowners, tourists, and tour guides became apparent. We believe that understanding the surface and subterranean holistically can guide protection and management of the resources within tropical forests and caves, especially in the face of expanding urbanization in Quintana Roo.

Tree roots emerge from conduits in the cave ceiling, sometimes extending through the floor or sprawling out along the floor. Several roots come in contact with water in the caves, which is an important water source for some tropical trees.

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USING BAT GUANO FROM CAVE SPRINGS CAVE IN NORTHERN ALABAMA TO RECONSTRUCT MOISTURE PATTERNS THROUGHOUT THE HOLOCENE.

Alexandra Tsalickis[1c], Matthew Waters[1], Joshua Campbell[2], Martin Medina[3]

The need to understand long-term precipitation patterns in the southeastern United States is of great concern considering population increases, climate change, and other environmental stressors. Current management strategies are typically based on modern records spanning the past ~50 years, forecasting models based on these records, and dendrochronology records spanning the past hundreds of years. One scientific approach to tracking moisture regimes over millennial timescales which has received very little attention to date is the study of bat guano deposits in cave systems. Guano deposits are common in multiple caves systems throughout Alabama and the southeastern US, and their isotopic compositions have been shown to track moisture and precipitation. Here, we present a 9,000-year record of moisture and rainfall periods based upon stable isotopes ($\delta^{15}N$, $\delta^{13}C$, $\delta^{2}H$) in a guano core collected from Cave Springs in Priceville, Alabama. Moisture was inferred from carbon and nitrogen stable isotopes showing alterations between C_3 and C_4 plant abundance indicating changes from cooler to warmer environments, respectively. Deuterium was measured from bulk guano and used as an evaporation/precipitation measurement. Results were compared to other paleoclimate records such as pollen from lake sediment cores and provide evidence for the Holocene Climatic Optimum, as well as periods of changing precipitation throughout the Holocene. This study suggests that future research investigating guano deposits from caves can provide a unique and long-term record of local paleoclimate.

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SINKHOLES – BIODIVERSITY HOTSPOTS OF EPIGEAN TERRESTRIAL KARST ECOSYSTEMS ON THE HOOSIER NATIONAL FOREST

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Sinkholes are ecotones in karst ecosystems that connect surface communities to underlying caves. Between 2015 and 2017, 26 sinkholes distributed in 12 tracts of the Hoosier National Forest (HNF) in southern Indiana were surveyed for fauna. Each sink was visited four times at intervals of about 3 months to provide a view of faunal occurrence through the seasons, for a total of 104 visits. The detailed results of this project are being published elsewhere, with the research involving the biological community appearing in the *Journal of Cave and Karst Studies* (Lewis, Milne, Stephen, and Dourson, in press) and the environmental section in the *Proceedings of the Indiana Academy of Science* (Lewis, Lewis, and Dunlap, in preparation). The discussion here is intended to bring the highlights of the project to the attention of the karst managers attending NCKMS 2019, without encroaching upon the substance of the manuscripts being published.

The evaluation commenced with measurement of the sinkholes, including their physical dimensions and environmental parameters such as temperature and relative humidity. Organic matter was collected and weighed from a 0.25m^2 quadrat area of each sinkhole floor (Fig. 1), then the invertebrates present were extracted by use of a Berlese funnel.

Five target groups were selected for detailed identification: land snails, terrestrial isopods, spiders, pseudoscorpions, and millipedes. A total of 140 target species were identified including 31 gastropods, 14 millipedes, 3 terrestrial isopods, 83 spiders, and 9 pseudoscorpions. Some species previously known only from caves were found, including the pseudoscorpion *Kleptochthonius griseomanus* and the millipede *Conotyla bollmani*. Another pseudoscorpion, *Chitrella* sp., was the first record of this genus from Indiana and is probably an undescribed species. Also discovered were new state records for 12 species, e.g., the millipede *Cleidogona unita*. Faunal diversity was positively correlated with the quantity of deciduous forest leaf litter on the sinkhole floor. Sinkholes in fields or pine plantations had lower biodiversity than those in deciduous forests.

Sinkhole floor habitats were found to have significantly greater biodiversity than the surrounding habitat beyond the rim of the sinks where controls were placed. Reasons for the greater species richness included higher habitat heterogeneity, greater depth of leaf litter and buffered environments as compared to the surrounding outer rim areas. The controls each had only two target species whereas the sinkholes ranged from 3 to 38 species (mean 18).

Concerning the environment of sinkholes, the floors had temperature and relative humidity intermediate between surface and cave environments. During the summer, all sinkholes were

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Figure 1. Salisa Lewis preparing a leaf litter sample for Berlese extraction, collected from a sinkhole located in a pine plantation in the Deam Wilderness. The sample is removed from a $0.25m^2$ quadrat on the sinkhole floor and then weighed. Sifting decreases the amount of material to be extracted in the Berlese funnel without significantly decreasing the invertebrate sample. The sifted sample is returned to the laboratory for processing.

cooler than the surface and humidity was higher (Fig. 2), with some sinkhole floors approaching the temperature of caves (around 55° F) and saturated humidity of 100%. In winter temperatures dropped, but were less variable than the surface and remained higher than the ambient surface temperatures during the coldest days.

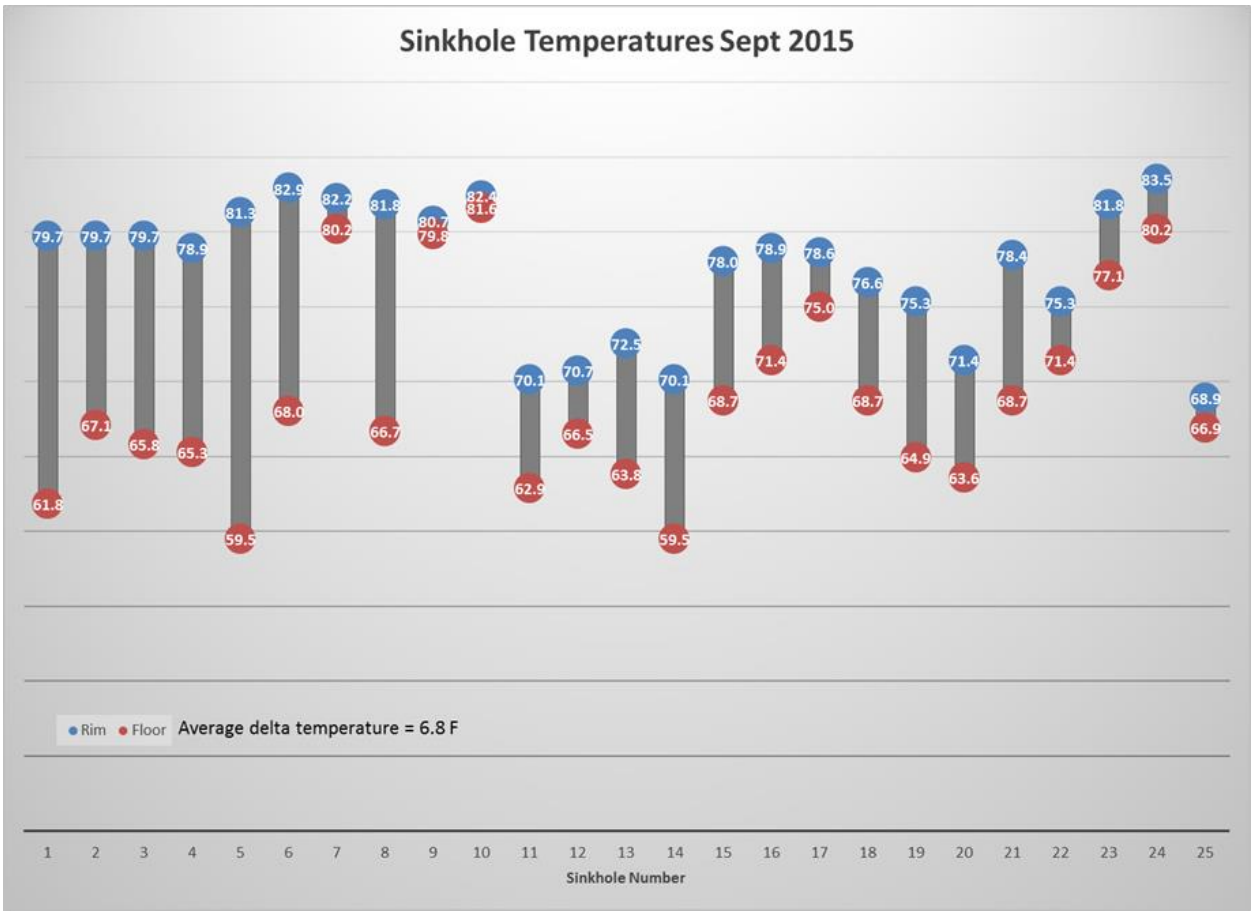

Figure 2. Comparison of differences in temperature at sinkhole rims (top numbers) and floors (lower numbers) measured in late summer 2015. In all cases, the sinkhole rims had higher temperatures than the adjacent floors.

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This project was funded by the U.S. Forest Service, Hoosier National Forest, Bedford, Indiana. Our greatest thanks go to Steve Harriss, the karst coordinator for the HNF, who conceived of the project, facilitated its funding, suggested sites, and arranged for logistical support in a forest where some of the project sinks were many miles from the nearest road. Likewise, Ron Scott, the Lands and Minerals coordinator for the HNF, provided field and logistical support. Charles Boswell kindly provided transportation to the remote Bull Creek sinkholes on Mogan Ridge. As always, the support of the HNF Forest Supervisor, Mike Cheveas, is appreciated in our work on the national forest.

THE BUTLER HOLLOW PROJECT IN MISSOURI

R. Scott House[1c], Michael Sutton[2]

The Butler Hollow area on the Mark Twain National Forest (MTNF) in Barry County, Missouri is not an orthodox mining district – the past mining activity is a remarkable story of fraud and naivety involving at least five caves, in a highly unlikely search for radium and perhaps silver as well. The activity left several caves with artificially excavated entrances and passages, which can be hazardous to the public. Because of this past use, the US Forest Service classifies these mostly natural caves as mines, and are obligated to control access for public safety. Since most of the caves house bat populations, bat-friendly gates were required. MTNF entered into a cost-share agreement with Cave Research Foundation to not only gate the mined caves, but to also search for other potential mining sites on the Cassville sub-district and to perform mapping and biological survey of caves throughout the sub-district. The project began in 2014. Gating, headed by Jim Cooley, began in October 2015 and was completed in June 2019, with the construction of 12 bat gates on four caves and one mine. The project has also resulted in a thorough documentation of caves throughout the sub-district. Of the 147 known caves, more than 80 were first recorded during this project. Most of the caves are small, but range up to 2600 feet (800 m), and include many biologically and archeologically significant sites.

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EVALUATING CAVE GATE COMPROMISES AND RECONSIDERING ALTERNATIVES

Cory Holliday[1c], James Wolfe Kennedy[2]

Cave gates are an important and constantly evolving tool to protect caves, the species that live in them, and other resources from anthropogenic threats. Land managers and cave gate builders evaluate potential and observed collateral impacts of cave gates as well as long-term management variables, including cave gate lifespan. A steel fence designed by Roy Powers and recently modified by Jim Kennedy offers a new option that may be preferential for particular caves and entrances. This design was constructed for the first time at an important Tennessee bat cave in the summer of 2019.

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CREATE QUICK 3D WORKING MAPS WITH CAVEWHERE

Philip Schuchardt[1c]

Cave, where? Visualize caves here, with CaveWhere. CaveWhere is an open-source, cross-platform (Windows, MacOS, and Linux) software package for managing and visualizing cave data. Inspired by the need to generate working maps on caving expeditions, CaveWhere can warp and render 2D paper sketches in 3D. Once sketches of surveyed caves are uploaded in CaveWhere, CaveWhere can export high-resolution working maps for drafting, from any viewing angle. Additionally, CaveWhere can produce plan view maps, and create a projected cave profiles along user specified planes from in-cave running profiles. Survey projects can utilize CaveWhere's lead database for visualizing and maintaining an active lead list, delineating areas of the cave not completely explored and requiring attention. CaveWhere seamlessly imports or exports data from existing survey projects that use various other cave survey software, including Survex, Walls, or Compass. Its flexibility and interoperability allow CaveWhere to enhance visualization of a cave's geometry without time-consuming modeling and drafting, facilitating rapid evaluation of cave resources and their potential. Consider integrating CaveWhere into your cave survey toolkit for both new and existing survey projects.

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CREATING A HIGH-RESOLUTION SIMULATION OF THE TIMPANOGOS CAVE SYSTEM USING A TERABYTE SCALE LIDAR DATASET

Blase LaSala[1c], John M. Kemeny[1], Cami McKinney[2], Andy Armstrong[2], Joshua Aaron Levine[3], Tyson Swetnam[4], Misha Kazhdan[5], Nicholas Steele[6], Kelly Swift[2], Kirsten Bahr[2]

Point clouds are a widespread method for digitizing real world objects. While this is in-part thanks to advancements in technology and lowering cost of equipment, the ability to render large mesh datasets at high resolution has been limited by hardware. This limitation can make these data difficult to utilize unless the resolution is reduced, which results in a loss of small-scale features. However, when it comes to underground spaces such as caves, the preservation of these small-scale features can be vital for geological characterization, safety, and resource management. In 2015 and 2019, a 22-billion-point cloud of the Timpanogos Cave system was collected using 520 terrestrial LiDAR scans. Its resolution is high enough to resolve sub-centimeter scale cave formations, such as helictites and soda straws. A Cooperative Ecosystems Studies Units (CESU) agreement between the University of Arizona and Timpanogos Cave National Monument was enacted in 2018 to develop this terabyte scale dataset into an interactive simulation for use in research and public outreach. The methodology and challenges processing this dataset are summarized. Using high-performance computing (HPC) solutions, python scripting, and meshing algorithms adapted for clouds exceeding several billion points, a model that preserves the delicate formations for which the system is famous can be rendered using today's hardware. A beta version of Timpanogos Virtual will be featured, allowing users to explore the cave system in virtual reality. A live demo for audience members to try after the talk may also be made available.

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THE IMPORTANCE OF A KARST CLUB IN HIGH SCHOOL

Hailey Raye Richardson[1c], Steve Ahn[2], Aaron Napier[2]

The Karst Club has been at Holston High School for five years, giving students access to experience and knowledge of caving that is not available in most schools. Holston High School is located in a small Appalachian town, and like much of Appalachia, suffers from a lack of opportunity and economic prosperity. Talented youth tend to leave the area due to the perception that there is very little for them here. Appalachia's riches lie in the landscape and literally in the land. Unfortunately, many students take the region's natural gifts for granted and miss out on an important reason to keep their own natural gifts in the area. The Karst Club is an organization whose goal it is to connect students with the wonders of the land around and below them in an effort to fully develop the next generation. Past and present students will discuss karst experiences, the impact of the club on their own lives, the philosophy of the leadership and development aspect of the club, and the issues involved in running such a club in a high school setting.

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OPTIMIZING KARST FEATURE CHARACTERIZATION: INTEGRATING NON-INVASIVE GEOPHYSICAL METHODS WITH INVASIVE GEOTECHNICAL SAMPLING

Johanna Vaughan[1c]

Undetected karst features may be inadvertently damaged by land disturbance and result in further development or alteration, as well as substantially increased land development costs (e.g., removing rock pinnacles, sinkhole mitigation). Invasive geotechnical sampling provides valuable but discrete data for karst features and may be cost-prohibitive or constrained by physical, ecological, and regulatory barriers. Non-invasive geophysical methods combined with geotechnical sampling is beneficial for characterizing potential karst, which can help protect features from unintended impacts of development by evaluating their spatial subsurface extents. Specifically, electrical resistivity imaging combined with invasive sampling provides direct observational data and reliably extrapolated interpretations. Remote sensing (e.g., electrical resistivity imaging) acquires non-destructive data related to subsurface physical property distributions for rendering subsurface mapping. For example, georeferenced electrical resistivity profiles calibrated by a nominal drilling data-set can cost-effectively elucidate subsurface bedrock topography and karst expression. Combining electrical resistivity imaging and invasive drilling data with precise Global Positioning Systems (GPS) and Light Detecting and Ranging (LiDAR) data, via industry-standard platforms such as AutoCAD, ArcGIS, or Google Earth, provides powerful and cost-effective risk-management and enhanced resource protection for karst environments.

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LIDAR-DERIVED ELEVATION MODELS AND IMAGERY AS TOOLS FOR KARST FEATURE MAPPING AND MANAGEMENT

Daniel H. Doctor[1c]

Management of karst resources begins with an inventory of the geomorphic and hydrologic features that comprise a karst system. The inventory of surface karst features is obtained via examination of surface topography and through field verification. Common challenges to obtaining this inventory are thick vegetation that obscures small landforms and limited access to remote locations. In 2014, the U.S. Geological Survey (USGS) established the 3D Elevation Program (3DEP) for acquiring airborne light detection and ranging (lidar) elevation across the entire U.S. (Fig. 1), with base specifications of 1 m horizontal resolution and 10.0 cm or better bare-earth vertical accuracy. Digital elevation models (DEMs) produced from lidar data have since revolutionized the mapping of karst regions, and by extension, the scope of their management. Within geographic information system (GIS) software, semi-automated tools have been developed for the digital extraction and morphometric analysis of closed depressions from lidar DEMs. Many additional sinkholes (typically tens of percent or more) can be identified using lidar imagery than using closed contours on traditional 1:24,000 scale USGS topographic maps. When combined with digital geologic map data, lidar elevation imagery can be used to identify previously unrecognized karst development in geologic units less prone to solution. In addition, automated hydrologic routing tools can be employed to define contributing areas to sinkholes and to illustrate ephemeral surface flow paths that are often not represented on traditional topographic maps. Finally, the enhanced visualization of lidar-derived bare-earth topography alone provides an excellent means for public awareness, education, and management of karst regions.

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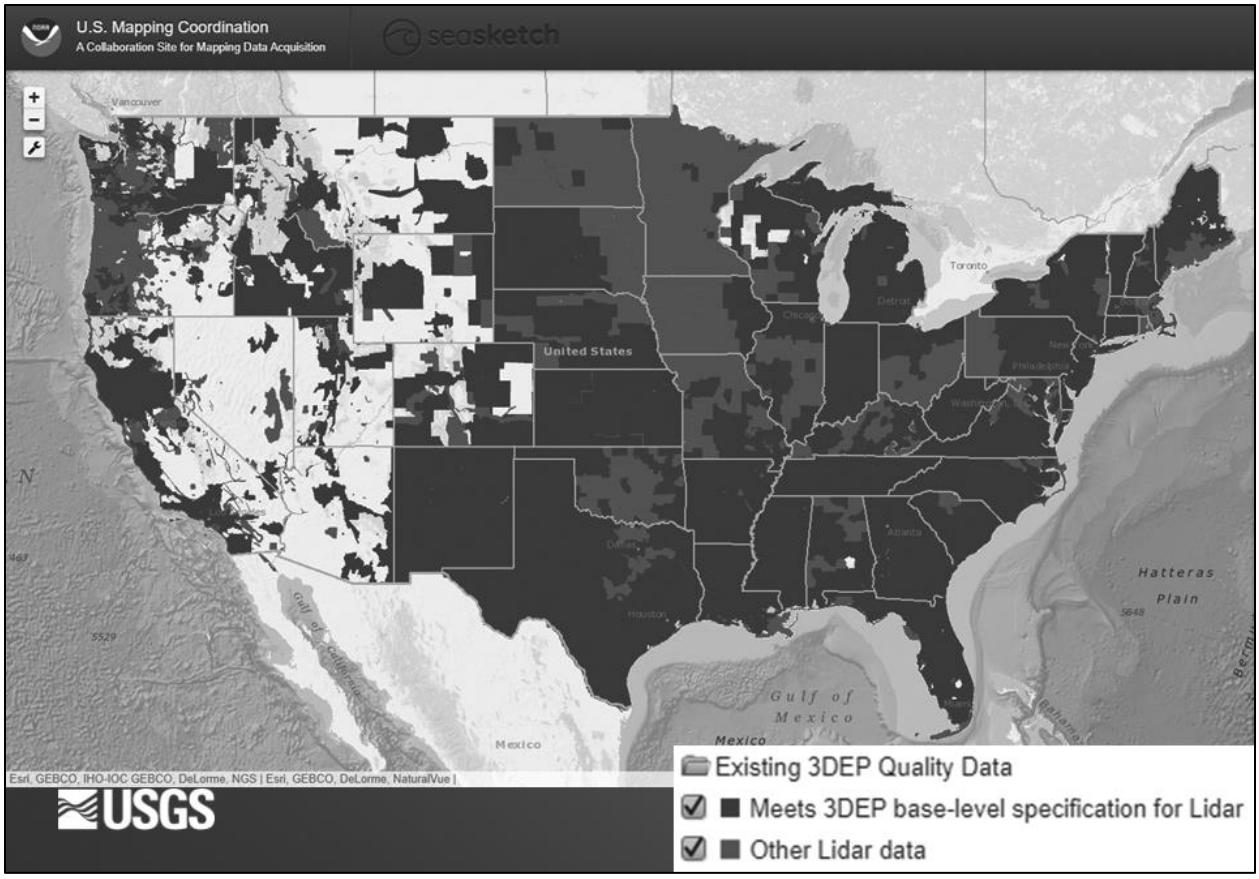

Figure 1. Lidar coverage across the conterminous United States as of November 2019. Elevation data and imagery may be downloaded from the U.S. Geological Survey National Map website: https://viewer.nationalmap.gov/basic/ (accessed November 4, 2019)

INITIAL REPORT, OUTSIDE INFLUENCES ON CAVES PROJECT, NEW YORK.

Robert Simmons[1c], Morgan Ingalls[1], Mitchell Berger[1]

The Northeastern Cave Conservancy, Inc. (NCC) has begun a multi-part assessment to better inform management of its caves in the wake of white-nose syndrome (WNS) and the listing of the Northern Long-Eared Bat as threatened. The NCC owns nine cave preserves containing sixteen caves, many of which serve or served as bat hibernation sites. The New York Department of Environmental Conservation (DEC) has performed bat surveys at NCC caves, within the constraints of budgets and manpower. WNS is believed to have reduced bat populations in the caves of the northeast by greater than 90%. Unauthorized winter incursions into NCC caves are suspected, which could result in disturbance of remnant and recovering populations. To assess the caves as hibernation sites, obtain environmental data and determine if unauthorized winter incursions occur, a basic data collection effort is progressing to monitor the entrances to the caves through the fall swarming, winter hibernation and spring emergence periods, monitor the presence of light to assess unauthorized visitation and collect long-term subsurface temperature and humidity conditions and variability. NCC obtained a grant through the DEC Conservation Partnership Program, administered by the Land Trust Alliance to purchase instrumentation, and support equipment. The purpose is to assess the suitability of NCC caves as recovery sites and inform management options. 2018-2019 data will be shared, as will materials and methods used, logistical issues and an overview of a science project using a volunteer workforce will be discussed, as will future plans.

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COLLABORATIVE MONITORING STRENGTHENS MACRO-SCALE ASSESSMENTS OF WHITE-NOSE SYNDROME IMPACTS FOR NORTH AMERICAN BATS

Tina L Cheng[1], Jonathan D. Reichard[2c], Jeremy T.H. Coleman[2], Theodore J. Weller[3], Wayne E. Thogmartin[4], Brian E. Reichert[5], Winifred F. Frick [1], and the NABat Colony Count Consortium

In order to understand macro-scale population dynamics and impacts from landscape-level perturbations, monitoring at broad scales is imperative. White-nose syndrome (WNS) has caused severe, local declines and extirpations in several species of hibernating bats throughout North America. We used annual winter counts to assess bat colonies in caves and mines to examine macro-scale impacts of WNS on North American bat species. Data were contributed by state, provincial, and federal biologists who have worked with cavers and other partners to count bats in winter colonies for decades. We used winter count data for five species of hibernating bats collected in the US and Canada at over 200 sites across 25 states and provinces, and spanning 23 years from 1995-2018. Our study highlights the strength of macro-scale assessments that can only be derived from broad-scale monitoring efforts, and which are needed to implement greater global, national, and state/province-level protection for the most impacted species. The North American Bat Monitoring Program (NABat) was initiated in 2015 as the first broad-scale coordinated effort to monitor bat species across North America. Winter and summer colony estimates are an important part of NABat, and the consolidation of historic and current count data with standardized acoustic detection information through a uniform geographic framework will allow for robust analyses of bat population trends. NABat also provides an opportunity and support for local managers of cave and karst ecosystems to participate in the program and bolster understanding of the bat species using these habitats.

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HIBERNACULA MICROCLIMATES MEDIATE BAT SURVIVAL WITH WHITE-NOSE SYNDROME

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Microclimates vary within and between bat hibernacula and affect bat energy and water conservation during hibernation. Bat survival in the Eastern United States might be especially contingent upon microclimate selection now that *Pseudogymnoascus destructans* (*Pd*), the white-nose syndrome fungus, has invaded the region, because fungal growth is strongly temperature-dependent. To test this hypothesis, we visited 22 hibernacula in Michigan and Wisconsin during early (November) and late (March) hibernation from 2014-2019—before, during, and after fungal invasion. During each visit, we quantified individual bats' roosting temperatures, fungal loads, and survival, focusing on a historically common bat species (*Myotis lucifugus*). We found that fungal growth rates were higher on bats that roosted in relatively warm microsites, and correspondingly, bats roosting in warm microsites were less likely to survive the winter. At the regional scale, average bat roosting temperatures declined 1ºC from pre- to post-invasion, because colder hibernacula served as thermal refugia from disease impacts. However, despite this strong selection pressure, the majority of bats continued to roost at the warm temperatures associated with low bat survival. Managing microclimates that serve as ecological traps, sinks, and refugia might mediate future bat population declines due to white-nose syndrome.

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EXPLORING THE PITFALLS AND POTENTIAL OF WHITE-NOSE SYNDROME TREATMENT STRATEGIES

Pete Pattavina[1c]

Since its discovery nearly fifteen years ago, the Eurasian fungus *Pseudogymnoascus destructans* (Pd), the pathogen responsible for the bat disease white-nose syndrome, continues to spread across North America, killing millions of native bats naïve to its effects. The U.S. Fish and Wildlife Service spends approximately $5 million annually through its white-nose syndrome program to understand host-pathogen dynamics and perform disease surveillance, and more recently to develop expanded field and laboratory trials for control of *Pd* to increase survivorship of infected bats. This is an overview of recently funded research and field trials, as well as a discussion of the constraints that face wildlife and land/karst managers in the treatment of animals and subterranean habitats that have sensitive ecosystems and experience significant recreational visitation.

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THE USE OF DYE TRACING TO DEVELOP A MITIGATION AND RESPONSE PLAN FOR TWO KARST-BASED PUBLIC WATER SUPPLIES IN AUGUSTA COUNTY, VIRGINIA

Robert K. Denton Jr.[1c], Joshua D. Valentino[1]

Construction of buried infrastructure presents potential impacts to karst aquifers upon which local communities depend for drinking water. Therefore, it is important to identify any features that could be insurgences for contaminated water generated by land-disturbing activities. Two public water supplies were identified that could be potentially impacted by the construction of the Atlantic Coast Gas Natural Gas Transmission Pipeline: Gardner Spring, which supplies half the drinking water for the City of Staunton (pop. 24,528); and the well and springs of the Town of Deerfield (pop. 132). Dye tracing established a hydrologic connection between Gardner Spring and a sinkhole located approximately 4.1 miles to the south. Travel time of less than 12 days suggests conduit flow. In contrast, dye placed in a sinkhole closer to the spring was traced to several other locations, but not to Gardner spring. Both injections were within the spring's designated source water protection area, delineated by a consultant using fracture trace analysis, geology, and topography. However, our results show that only the southern point is in the recharge zone for Gardner Spring, and suggest the karst aquifer network in this region contains several discrete hydrogeological compartments. At Deerfield, dye which was placed in the Hamilton Branch above a sink located 0.7 miles to the west was detected at the water supply within 24 hours. Based on these results, we developed a site-specific plan for each water supply to preclude potential impact to the karst aquifer, as well as specific response and notification plans to coordinate with the municipalities dependent on the aquifer for potable water. Our study demonstrates that dye tracing is an essential component of any meaningful delineation of recharge areas in karst.

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USE OF TIME-LAPSE PHOTOGRAPHY TO MONITOR SEASONAL ICE FORMATION IN CASTLEGUARD CAVE, ALBERTA, CANADA

Gregory Horne[1c], Kathleen Graham[2], David Critchley[3]

Abstract

Canada's longest cave, Castleguard, has provided past and present generations of cavers with unexpected seasonal ice and hydrology surprises that block or threaten access to the cave. During early days of exploration in the 1960s, summer flooding quickly shifted caving activity to late winter and early spring when water levels in the cave were the lowest.

By the mid 2000s, cave hydrology was changing, massive summer flood events occurred and thick ice built up that prevented access. Conditions are now so unpredictable that pre-expedition reconnaissance visits are mandatory to check if the cave is enterable. Even with this level of preparation, groups are being turned back due rapid changes in only a couple weeks between visits.

A project to monitor ice levels began in 2015 by Kathleen Graham. Initially each monitoring session involved a 40-km round trip ski on a glacier, whiteout conditions, and avalanche hazards. But the novelty of measuring ice thickness and not being able to actually do any caving because of the ice blockage led to an alternate monitoring method, time-lapse photography.

The monitoring site required equipment for unattended operation of a year, underwater housing for 15 m deep, below freezing temperatures, and powerful summer flood pulses, all with a shoe string budget. While at it, time-lapse monitoring of the entrance resurgence activity would be a bonus to capture.

Combined with photography was collection of temperature data outside and in the cave. Could roadside weather data be a proxy to predict cave ice levels without a pre-expedition visit?

Introduction

Although known since the 1920s, the exploration of Castleguard Cave truly began in 1967. A tip from Jasper resident Red Creighton led McMaster University's Derek Ford and students to its entrance and the first of many years of discovery. The cave was pushed into Thompson's Terror. The infamous flooding of the entrance series, subsequent wet suit spooning by Boon and Thompson, the narrow escape, and the at least 18-day continued resurgence of the cave has made legend and respect for Canada's longest cave.

That epic flood event led to Castleguard exploration being shifted from summer to late winter or early spring; minimal trail breaking, longer days, and moderating temperatures. This timing strategy worked very well for the most part. One trip in April 1990 was thwarted due to the entrance ice crawls being frozen too tight to pass through (still drafting). At that time, only once before had a build-up of ice blocked entry. The cave drafts inward in winter, drawing in the cold outside air to freeze pools and small inlet seepages. In the past this draft combined with low-flow seepage flow allowed for the passage to remain open, just barely.

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In 1994 Norwegian cavers had an eye-opening incident in the ice crawls. On their way into the cave a label tore off a bag being dragged on the ice. Three days later on the way out the label was discovered, visible, but covered by 3- to 4-cm of fresh ice build up. That's about 1 centimetre per day.

Many have experienced the ice crawls as being a tight and sometimes very wet, flat-out belly crawl. Removing helmets plus unpacking and moving one's kit through in garbage bags is the norm lately. Unfortunately, ice build up has recently blocked and or sealed off entry into the cave several times. The first recent heartbreaker was when Welsh cave diver (Martin Groves) and crew were repelled in April 2012 (Stenner, 2012).

Starting in 2015, Katie Graham rallied cavers to do monthly winter inspections of the ice crawls. Checks of the cave (February 13, March 13, and April 11) found the ice crawls were impassable on all three visits. The winter of 2015–2016 was much more favourable for access. Visits on December 20, January 16, and March 19 all found the crawls without restrictions, meaning easy passage with no squeezing. It appeared a full green light for an expedition arriving on April 9, 2016. However, signs of a recent flood event since March 19 had everyone spooked, no one even wanted to day trip into the cave, the trip was cancelled.

Katie has compiled the results of all these inspection reports with weather station data (temperatures, relative humidity, and snow depth) from the Parks Canada site at Parker Ridge into a report (Graham, 2016). A key recommendation of her report was to "install a waterproof robust camera and measuring stick for scale to observe the ice crawls throughout the season. Watch if ice increases dramatically at the same as snow depth decreases on weather station data. Remain open to other possibilities for ice build up."

Equipment Design

An extensive internet search was made to locate a pre-built camera and underwater housing capable of shooting time-lapse and be self sufficient for at least 6 months. Only one off-the-shelf possibility was discovered (www.harbortronics.com/Products/Hydrolapse), but is no longer available. Hydrolapse would have fit the bill, but its $5,350 USD price tag was over the top. The design of the Hydrolapse housing did however inspire Greg Horne to figure out a rugged method of constructing the shell.

The professional quality Reconyx (www.reconyx.com/product/PC-900-HyperFire-Professional-Covert-IR) wildlife camera model PC 900 has time-lapse, infrared flash function, temperature recorder, and a self-contained battery capacity of up to 12 months. With a cost of $650 USD, this was a realistic option. As of 2019 this model has been replaced by the HyperFire 2 Professional HP2X. Both models have a factory option modification of an external jack to input additional battery power thus extending deployment to 2 years.

Dave Critchley arranged through NAIT (Northern Alberta Institute of Technology) for several sections of 8-inch PVC potable water pipe be cut and machined square. The ASS (Alberta Speleological Society) purchased the ½-inch-thick plexiglass for the ends. Parks Canada provided the camera. Once a case was constructed, it was tested by submerging it 20 metres deep in a lake for a week. The anticipated maximum water depth in the ice crawls could be in the range of 10 to15 metres. After the housing passed the pressure test, experimentation with using the time-lapse function and flash through the plexiglass followed. Finally, a mounting and protective cage was built using angle iron recycled from a bed frame, Figure 1. The complete set-up weighs about 18 kg.

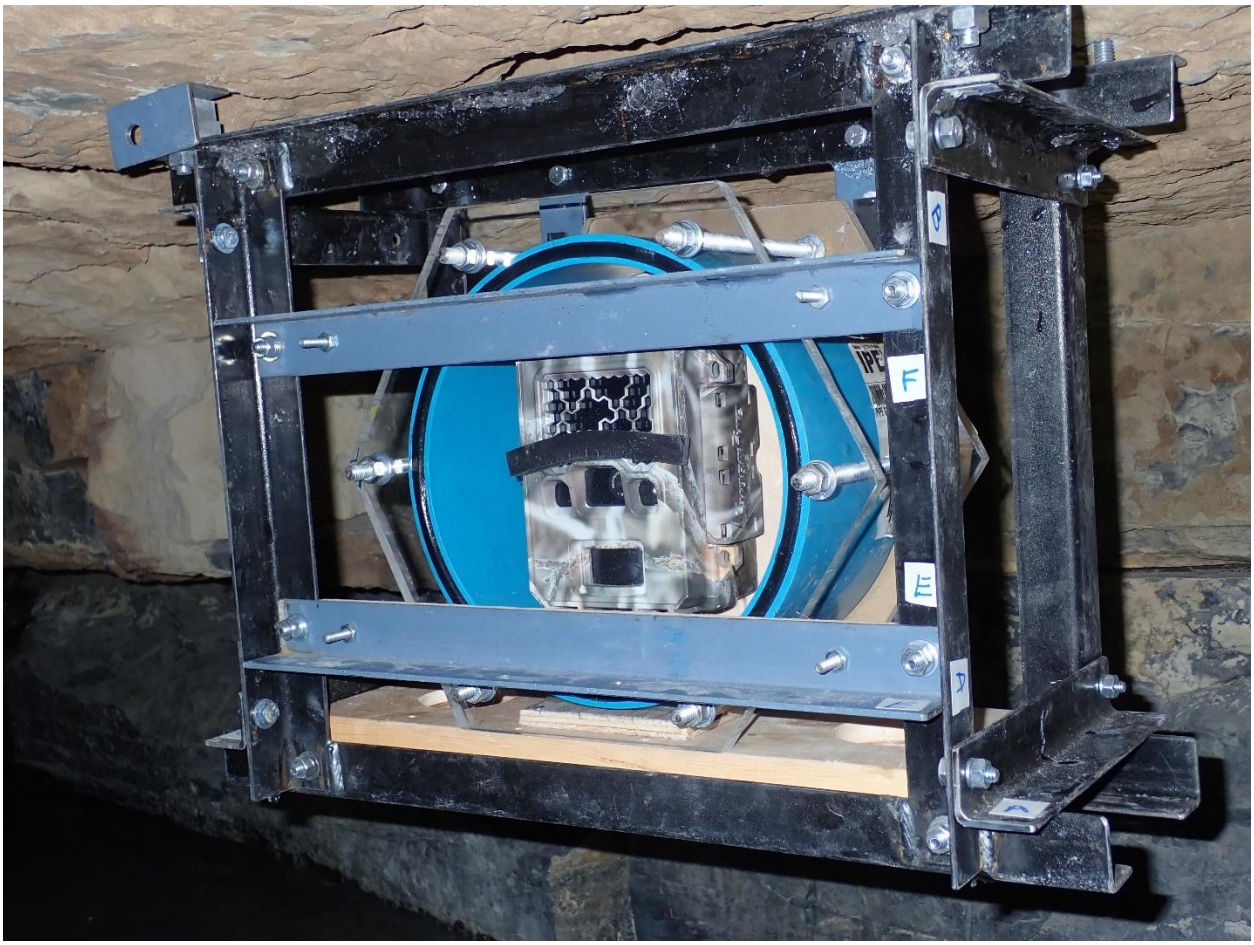

Figure 1. Underwater housing, Reconyx camera in angle iron frame mounted to cave ceiling.

NAIT loaned two Hobo Pro temperature and relative humidity (RH) data loggers. These loggers were placed on the north side of a large spruce near the entrance and high on the cave wall between the cave gate and the ice crawl flood zone. These data loggers performed two important functions. The logger outside will be used to compare the differences between the cave entrance area and the Parks Canada weather station near Highway 93, 15 kilometers away. Should a temperature and snow pack relationship with ice crawl buildup be developed, knowing how similar or different Parker Ridge and outside the cave are will give more insight. The data from the logger just inside the cave will be compared to the outside unit. When the inside temperature equals or nearly equals the outside, it means the cave is most likely drafting in. When the inside is significantly colder than outside temperature, then the cave in likely drafting out.

A second Reconyx camera was set up outside the cave pointing back towards the entrance. The goal here is to capture five images per day for a year as a time-lapse sequence of the general conditions outside and any flood or resurgence activity. If it works as planned, it will provide an impressive record of what happens at the mouth of Canada's longest cave.

Equipment Deployment

Access to Castleguard Cave is an all-day backcountry ski tour of approximately 20 kms over a glacier, moraines, and alpine meadows averaging 8 to 12 hours. Avalanche terrain assessment, whiteout navigation, and deep snow trail breaking add to the effort of reaching the cave. In December 2017, the initial equipment set was completed. Early season was chosen to ensure the maximum working space in the ice crawl area.

A heavy-duty angle iron frame was built to protect the underwater camera and secure it to the cave ceiling. Unsure of the potential currents and possibilities of underwater rock debris movement striking the housing, it had to be bolted to the ceiling, Figure 2. A battery powered hammer drill and 3/8-inch stainless steel wedge anchor bolts were used. The target ruler is a porcelain enamel-covered steel ruler used for aquatics water level monitoring. The ruler was bolted to the cave wall using ¼-inch stainless steel wedge anchor bolts, Figure 3.

Figure 2. Installing camera frame above ice floor.

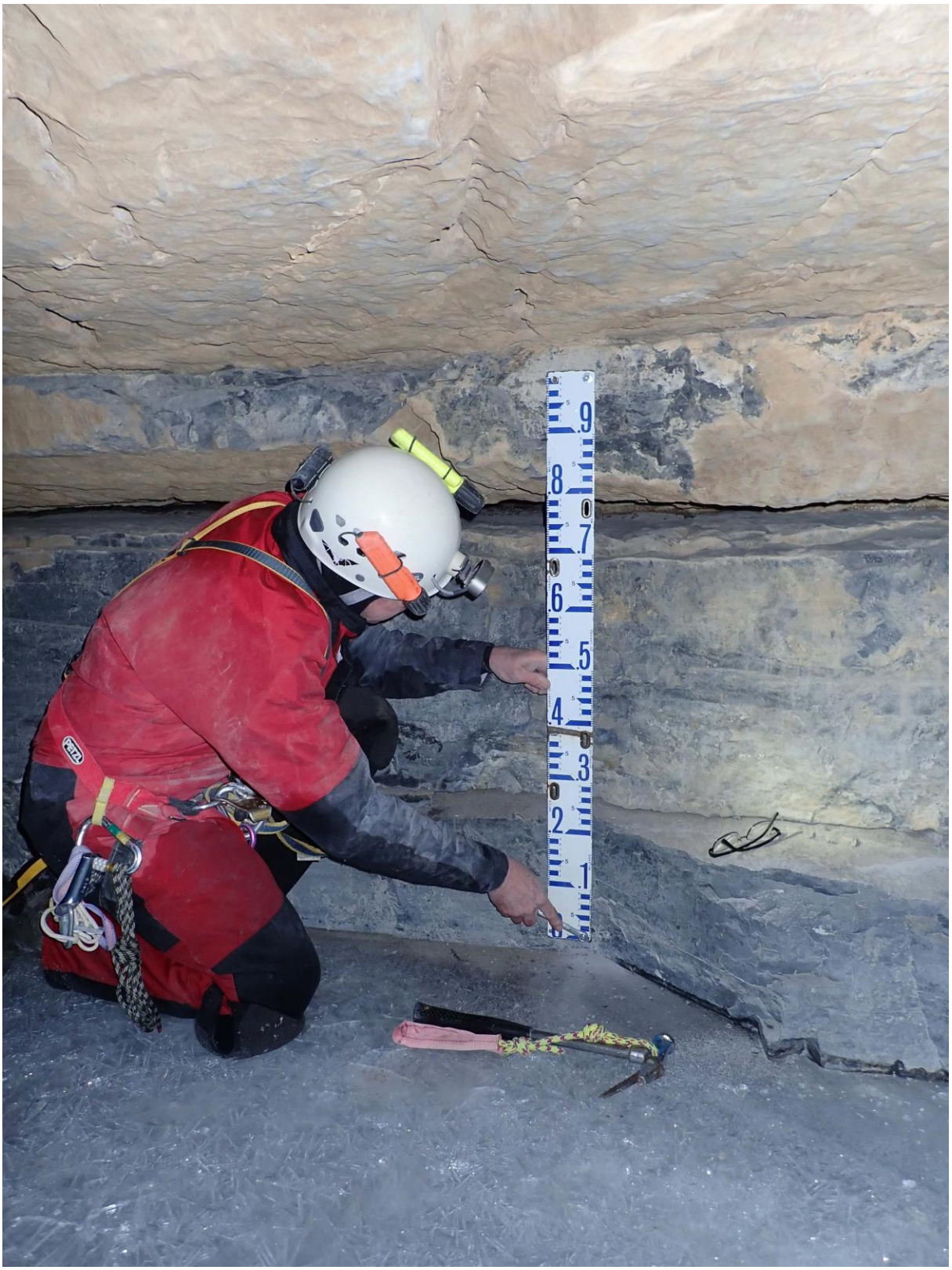

Figure 3. One-meter ruler target bolted to cave wall.

The Reconyx camera was programmed to take one photo per day using its infrared flash. Although powered by 12 lithium AA batteries, concerns existed whether the cool site temperatures (-10 to +5 C) and every picture using flash might exhaust the batteries before a year deployment was up.

The outside Reconyx camera, mounted to a tree, had a plywood shield or roof installed above it to prevent falling snow from building up and covering the camera. Five shots per day at one-hour intervals, 10 a.m. to 2 p.m., were taken using the in-camera time-lapse mode. The south aspect of the cave entrance dictated the best time of day for photography. With more experimentation to test battery life, additional images each day would more precisely capture duration of flood events.

Results

In January 2019, a return visit was made to check on the status/conditions of cameras and data loggers 13 months after deployment.

Both Reconyx cameras, underwater housed and tree mounted, operated on the time-lapse schedule as programmed without issues. The ruler used as the ice level measuring device for the underwater camera did provide an unexpected surprise. The printed numbers and markings are dark blue on white background. The Reconyx camera, in darkness, takes infrared flash black and white photos. Before deployment a test photo of the target ruler was not taken in the infrared mode. The resulting infrared photos wash out the blue numbers and markings to the point of becoming nearly invisible. Luckily, chips in the porcelain enamel, brass grommets on the ruler, and bedrock features beside the ruler allowed ice levels to be estimated using a normal flash photo of the ruler in place on the cave wall. This seemingly minor pre-deployment testing oversight nearly scrubbed the entire project.

The outside Hobo Pro data logger failed completely. As backup, the outside Reconyx camera records temperature on each image. Of these temperature readings, 10 a.m. is generally the lowest and 2 p.m. the highest; they were used to compare with weather station near the highway.

A detailed cross section of the cave passage at the historical pinch point (13 m from the wall ruler) was draw to scale when the January 2019 ice level on the ruler read 31 cm. The thought here was to estimate at what ice height on the ruler will the pinch point be too small to squeeze through. The cut off height will be in the range of 45 to 50 cm.

The 13-month deployment allowed for two early winter monitoring sessions (December 2017–January 2018 and December 2018–January 2019) of the ice build up at the ruler to be recorded by the underwater camera, Figure 4. A full start-to-finish cycle of seasonal ice was also captured by the camera, although it might not have been to the height of a blockage, Figure 5. The outside tree-mounted camera captured five resurgence flood events in the summer of 2018, each lasting 1 to 7 days, Figure 6. During each flood event, the underwater camera images went blurry with no view of the ruler or wall it is attached to. Unexpectedly, the sump where the underwater camera is located drained very quickly after a flood event, usually in a day. The outside temperatures, as recorded by the camera sensor, strongly indicated that when afternoon temperatures exceeded 20 C, the danger of flooding is high, Figures 7 and 8.

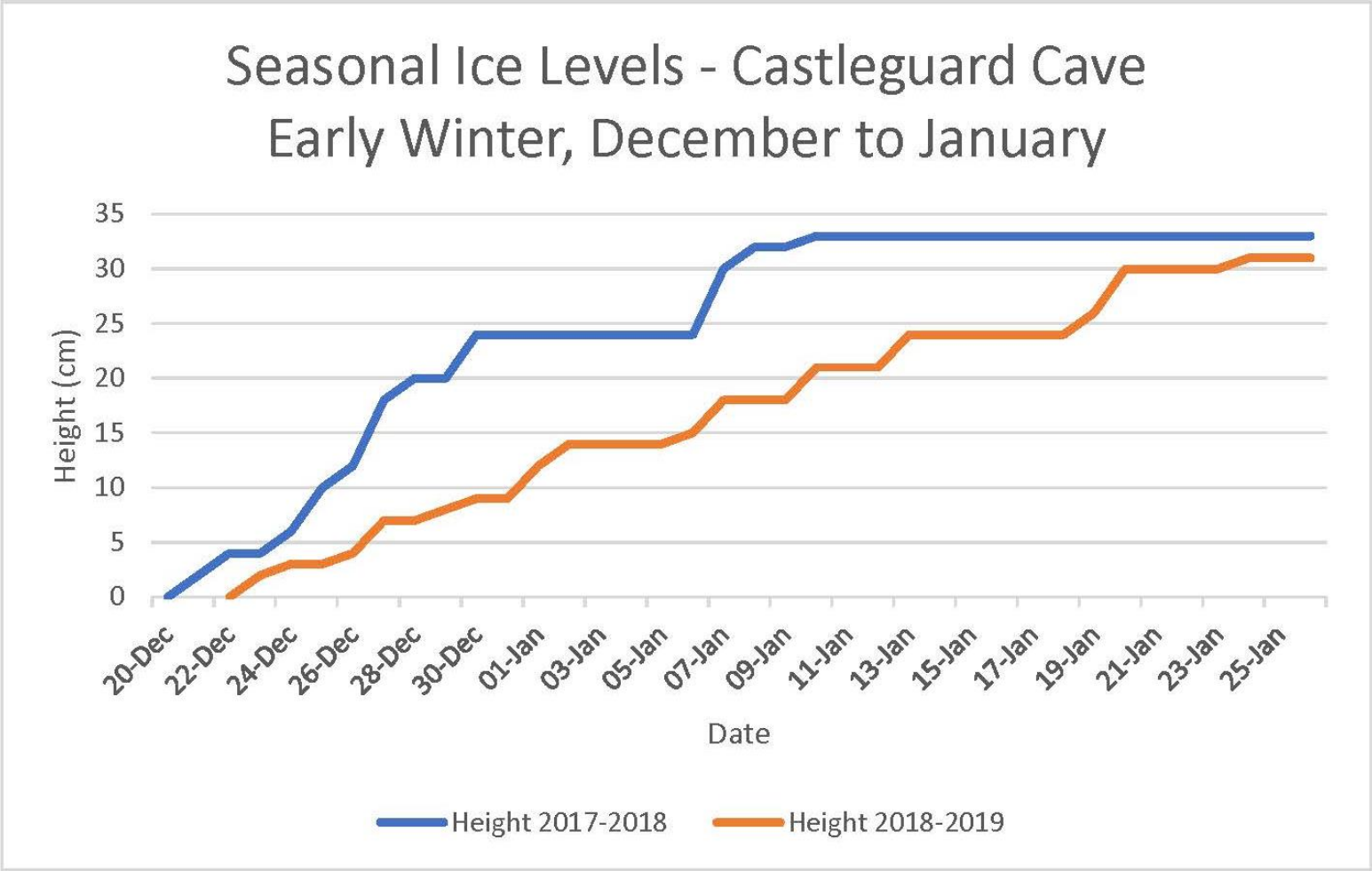

Figure 4. Early winter, December to January, ice levels, 2017–2018 and 2018–2019.

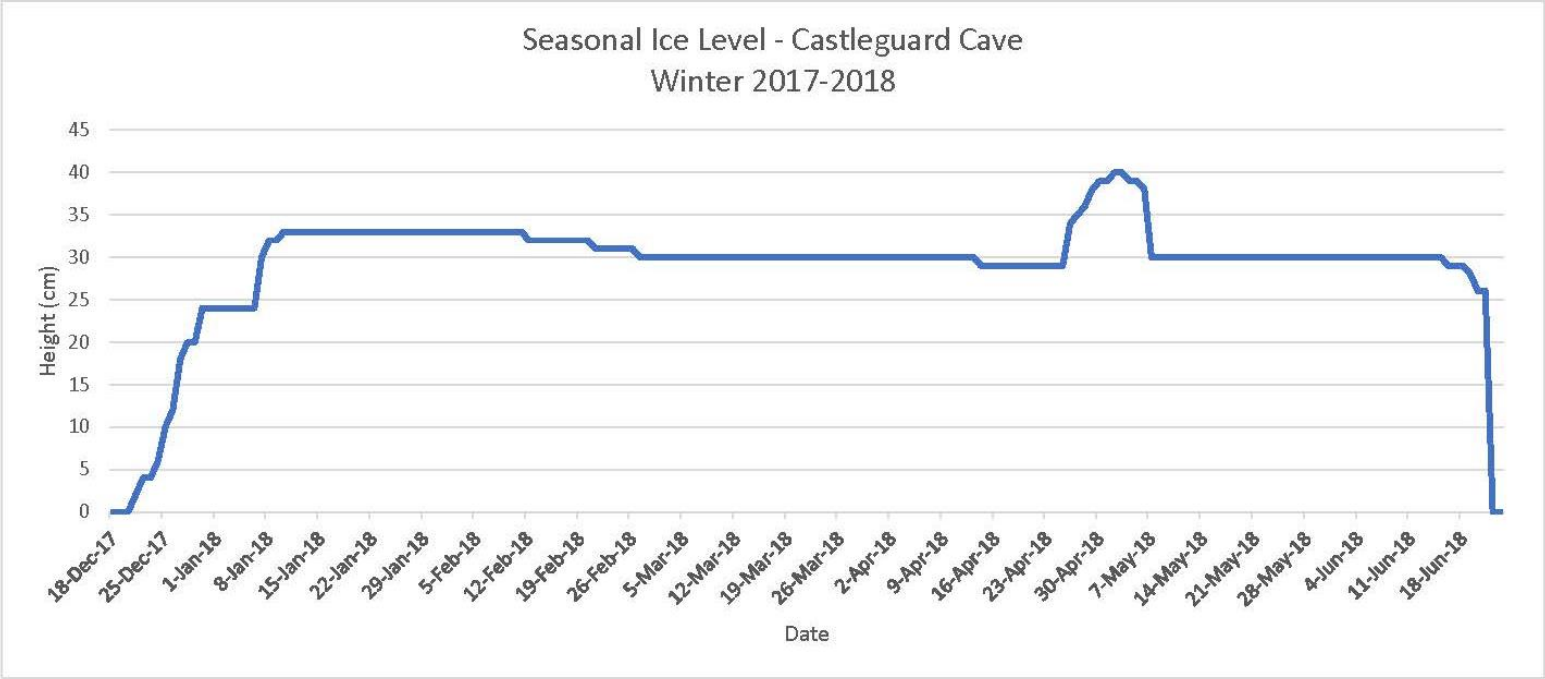

Figure 5. Ruler ice measurements of the full winter of 2017–2018.

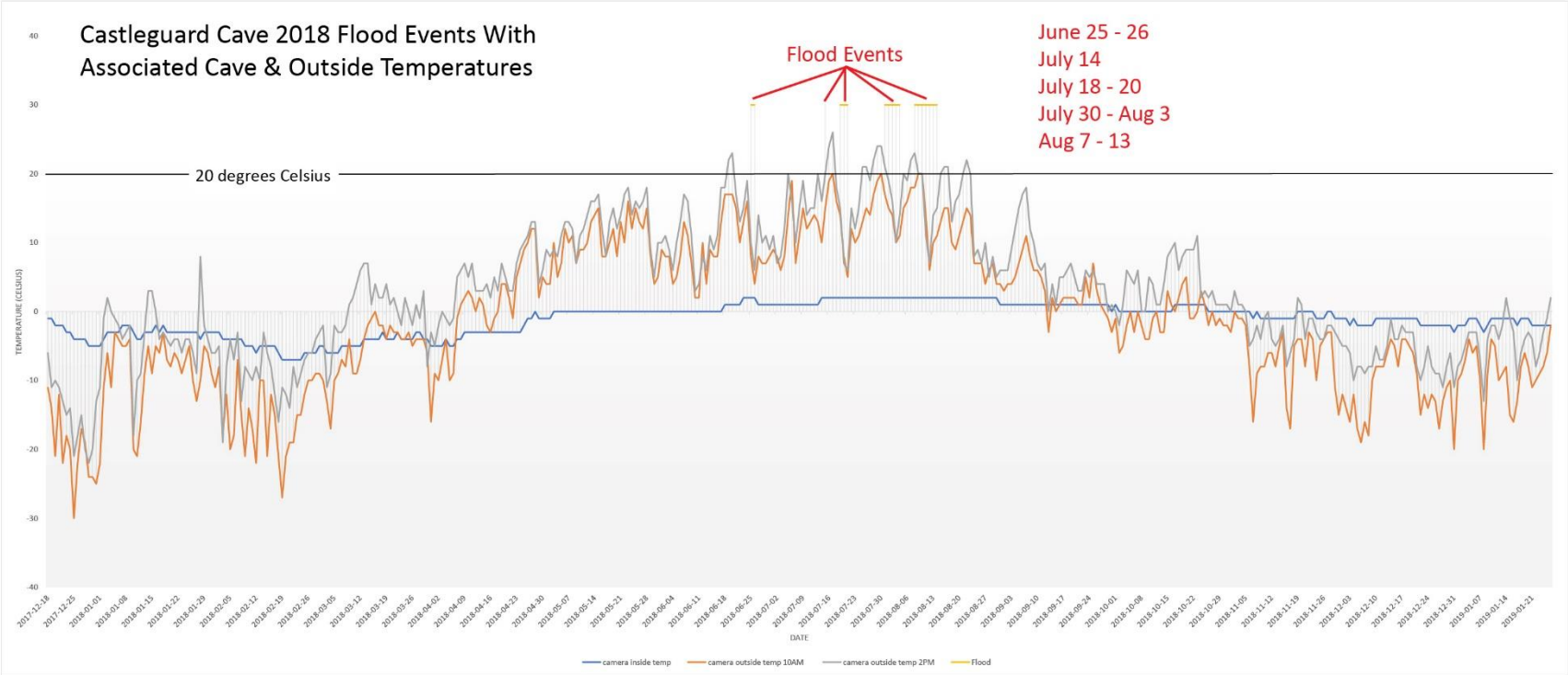

Figure 6. Record of flood events and associated temperatures inside and outside December 2017 to January 2019.

Figure 7. Example of outside time lapse image of resurgence flood event.

Figure 8. Example of outside time lapse image when cave is not in flood.

Statistical review of the highway weather station data did not tease out any obvious correlations between outside temperatures and or snow depth versus ice levels in the cave. Continued servicing of the time-lapse cameras is planned until at least 2021 to collect more data and potentially record an ice blockage event by the underwater camera. In the meantime, any major Castleguard caving expedition requires a reconnaissance scouting trip 1 or 2 weeks prior to determine if the ice crawls are passable.

Conclusions

The application of time-lapse photography to monitor cave hydrology using digital wildlife cameras has value for both data measurements and education/interpretive purposes. Testing of equipment at proposed setup locations/conditions is recommended. Opportunities for equipment theft or damage by environmental conditions and vandalism need to considered. Informative signage with equipment has proven with regular wildlife camera deployments to reduce public incidents of tampering and theft.

In the case of this project, site measurements of ice levels from photography could not be directly related back to local or remote climate records, at least over the very short duration monitored so far. The factors contributing to unpredictable seasonal ice deposition at Castleguard Cave will require more investigation before a reliable forecasting model is ready to use.

Project Contributors

Alberta Speleological Society: Plexiglass for camera housing, members to help carry and install equipment and visually monitor ice levels

Northern Alberta Institute of Technology: Water pipe material and machining, Hobo data loggers

Parks Canada: Wildlife camera and batteries, pressure testing of housing in lake

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HIGH-RESOLUTION MEASUREMENTS OF CAVE AIR CARBON DIOXIDE IN THE CONTEXT OF 30 YEARS OF CAVE AIR DATA FROM KARTCHNER CAVERNS, ARIZONA

Sarah A. Truebe[1c], Kevin D. Webster[2]

Abstract

Carbon dioxide (CO_2) concentrations in air within natural caves trend higher than atmospheric concentrations. CO_2 sources include dripwater degassing, soil CO_2 diffusion, organic matter decay, geothermal outgassing, and tourism. CO_2 levels in cave air are reduced by mixing with atmospheric air via natural ventilation processes. Cave ventilation is thought to be controlled by air density, driven by seasonal changes in temperature/pressure relative to cave air. Kartchner Caverns is a show cave in southern Arizona that exhibits annual CO_2 concentration cycles with highs in August/September and lows in January. Kartchner Caverns hosts 134,000 visitors every year and holds multiple tours per day that could influence CO_2 concentrations at higher frequencies than the routinely collected biweekly monitoring data. Thus, we used a single Omega AQM-102 CO_2 meter to obtain high-resolution snapshots of CO_2 concentrations in four key locations. Although our data are as yet insufficient to comment on the impact of tourism, we observed a strong correlation between ventilation and average surface wind speed but not temperature/pressure as measured by an onsite weather station. This suggests that an air density gradient created by temperature/pressure variability may prime the cave air system, but the addition of wind allows for more significant ventilation than by simple diffusion alone. Windiness may increase in southern Arizona with global change, which may lead to more frequent or deeper ventilation of Kartchner Caverns, suggesting active management of humidity levels into the future may be necessary.

Introduction

Kartchner Caverns is a developed cave in southern Arizona (Fig. 1). Since its discovery in 1974, utmost care has been taken to keep Kartchner Caverns as pristine as possible. When the cave was transferred to state ownership in 1988, baseline studies were undertaken to determine how much natural variability of temperature (air, soil, water), relative humidity, evaporation, carbon dioxide (CO_2), and Radon (Rn) was present before putting in trails, lights, and artificial tunnels (Buecher, 1999). Since the addition of trails, lights, and tunnels in the late 1990s, these same parameters have been tracked to ensure the continued health of Kartchner Caverns while 134,000 people visit the cave each year.

Cave air CO_2 concentrations (pCO_2) tend to be higher than atmospheric air (Banner et al., 2007; Breecker et al., 2012; Webster et al., 2018). The sources of CO_2 include dripwater degassing (Spötl et al., 2005), soil CO_2 diffusion from organic matter decay and root respiration (Tremaine et al., 2011), geothermal outgassing (Webster et al., 2017), and tourism (Dragovich and Gross, 1990). CO_2 decreases in cave environments through mixing with the atmosphere (400 ppm CO_2), a process known as cave ventilation or “breathing” (Breecker et al., 2012).

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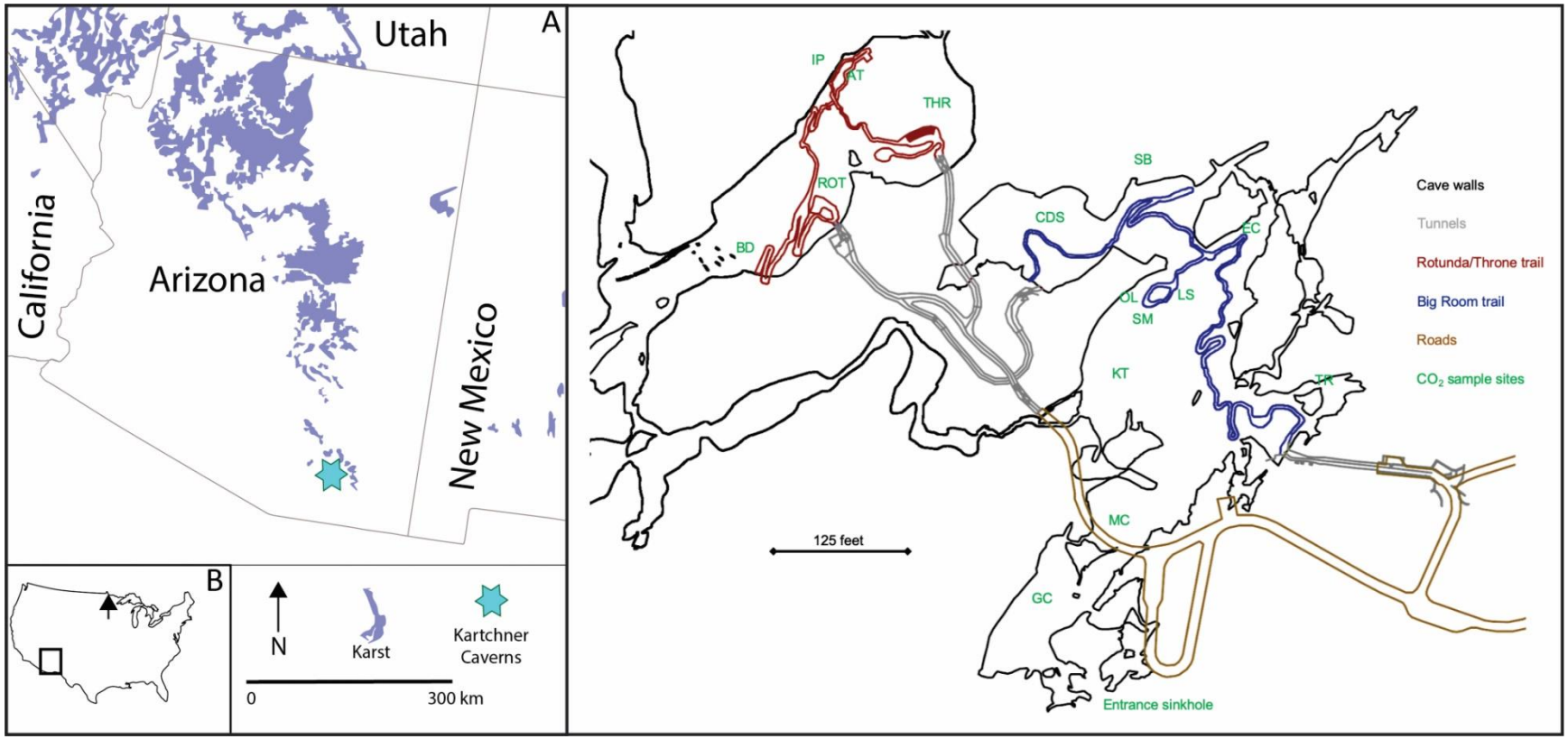

Figure 1. (left) Map of Arizona karst regions, including Kartchner Caverns, shown by the blue star. (right) Partial outline of the cave walls of Kartchner Caverns with CO2 measurement locations shown.

Cave ventilation is thought to be controlled by differences in air density. For caves with a single entrance, when outside air is colder than cave air, atmospheric air with a CO_2concentration of ~400 ppm will sink into the cave due to cold air being usually denser than warm air. When outside air is warmer than cave air, the cave will remain fairly stable with little to no ventilation. This gives rise to a pattern where many caves have higher pCO_2 in the summer or early autumn and lower in the winter, when they are actively exchanging air with the atmosphere. This simple pattern can be greatly complicated by cave morphology and the number and relative elevations of openings through which the cave can ventilate. Worldwide there are examples of caves that ventilate in the winter/cool-season, e.g., in Alabama (Lambert & Aharon, 2010), Texas (Banner et al., 2007), Ireland (Tooth & Fairchild, 2003), China (Cai et al., 2011), and Austria (Spötl et al., 2005) as well as some that ventilate during the summer/warm seasons, e.g., in Gibraltar (Mattey et al., 2010), Ireland (Baldini et al., 2008), Spain (Sanchez-Moral et al., 1999), the Czech Republic (Faimon et al., 2006), and China (Hu et al., 2008). Whether caves ventilate during the cool season or warm season can vary regionally on small spatial scales (Truebe, 2016).

Kartchner Caverns ventilates more strongly during the winter/cool season, leading to high pCO_2 in the late summer/fall and lower values during the winter (Fig. 2). This pattern is consistent across sites within the cave (Figs. 1 + 2), and across the 30 years of biweekly data (1989–2019; Fig. 3). Kartchner Caverns has an additional source of CO_2 in the form of tourism; however, this is not immediately apparent in the low-resolution data. Higher resolution measurements are necessary to begin to understand the effect of tourism and other variables on CO_2 trends in Kartchner Caverns.

Despite the long history of CO_2 monitoring in Kartchner, the specifics of air exchange within the cave and between the cave and the surface are not well understood. We deployed a CO_2 meter capable of recording CO_2 concentrations on sub-hourly timescales, and a meteorological station in the vicinity of the cave to understand the processes that influence cave breathing at Kartchner. We sought to understand the relationship of meteorological variables like wind speed, air temperature, air pressure, and air density to CO_2 concentrations at varying locations within the cave.

Methods

Spot observations of CO_2 have been collected since 1989 at 3 to 14 locations throughout Kartchner Caverns biweekly or monthly (Fig. 3). From the early 1990s until 2005, Draeger diffusion tubes and a Telaire T7001 handheld meter were used to monitor CO_2 concentrations in the cave. The Telaire meter was recalibrated in 2005 and was replaced in 2010. At that time, the condensing humidity in Kartchner Caverns may have interfered with readings. In June 2012 the Telaire was replaced with an Amprobe CO2-100, which has been in service since that date and is recalibrated at each use in atmospheric air.

High resolution CO_2 data were collected using a field-deployable data logging monitor (Omega AQM-102). The meter was ruggedized by developing a breathable field casing and modified to draw power from a 6-volt lead acid battery. Average CO_2 concentration data were logged every 6 minutes. Air temperature and relative humidity were also recorded by the instrument. Deployments of the CO_2 meter ranged from 1 to 3 weeks. The meter was selectively moved to different locations to understand how atmospheric variables influence CO_2 concentrations in different locations throughout the cave (Fig. 1).

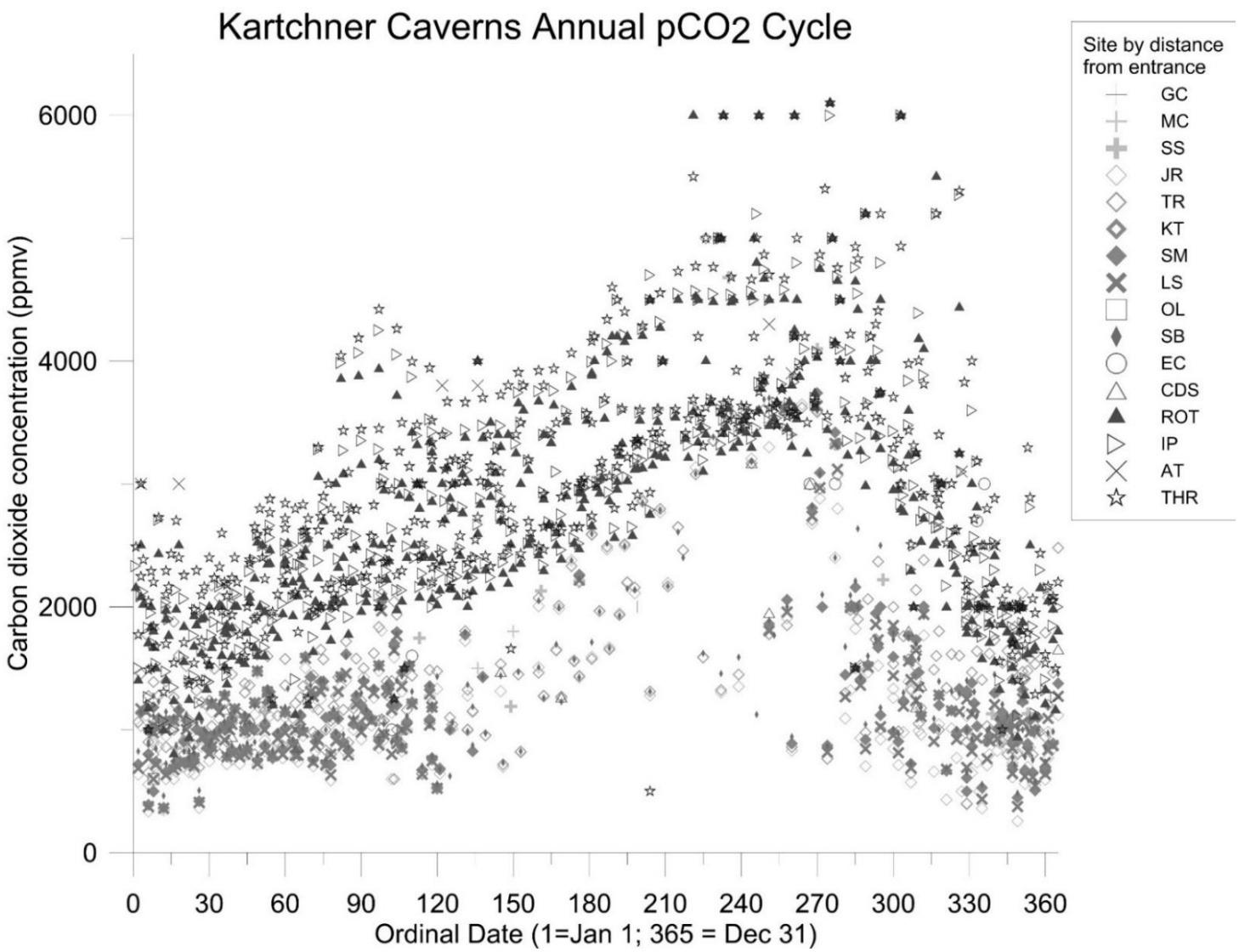

Figure 2. Annual cycle of pCO2 variability throughout Kartchner Caverns. Sites are shaded and arranged in terms of distance from the natural entrance with darker shades representing sites further from the natural entrance. Lower data density during summer is due to the Big Room closure to protect a *Myotis velifer* maternity colony.

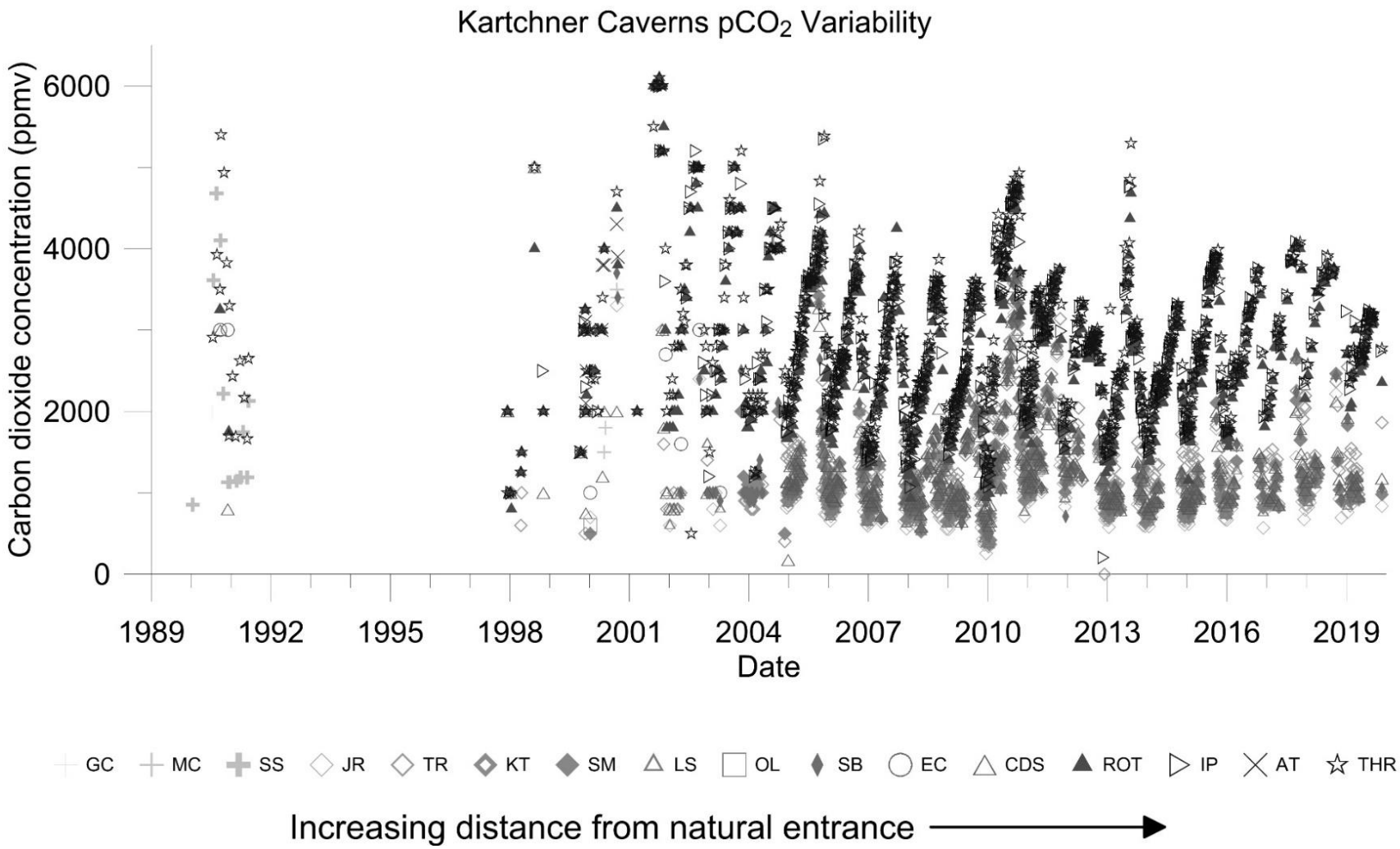

Figure 3. Time series of pCO2 throughout Kartchner Caverns from 1989–2019. Sites are shaded and arranged in terms of distance from the natural entrance with darker shades representing sites farther into the cave.

In locations where the CO_2 meter was exposed to atmospheric air (the sinkhole), the meter was set to autocalibrate once a week and designate the lowest observed CO_2 concentration as 400 ppm. In locations where the CO_2 meter was not exposed to the atmosphere once a week, CO_2 concentrations were observed to drift and had to be corrected. Drift over the entire course of measurement was corrected by measuring the CO_2 concentration of the atmosphere outside the cave before and after meter installation and creating a linear regression correction based on the initial and final atmospheric measurements.

Meteorological (met) data at Kartchner Caverns were measured by a weather station 375 m away from the sinkhole entrance (Vantage Vue, Davis Instruments Corp., Hayward, California, USA). The met station measured air temperature, wind speed, relative humidity, air pressure, and air density, and recorded the average of each variable at 30-minute intervals.

Analytical Methods

CO_2 concentrations and met data were recorded at different rates. This prevents a direct analysis of ordered pairs of CO_2 concentration data and met data. We therefore averaged the CO_2 data into 30-minute blocks that corresponded with the measurement intervals of the met station prior to all numerical analyses following the methods of Webster et al. (2015). Average CO_2 concentrations were calculated using the statistical computing application R (R Core Team, 2019).

Results

Long-term trends in cave-air CO_2

Over the 30 years that data have been collected at Kartchner Caverns, CO_2 concentrations varied between atmospheric levels and ~6,000 ppm (Figs. 2 and 3). Generally, pCO_2 is lower near the cave entrance and higher further into the cave. The annual carbon dioxide cycle peaks from August through October and is lowest from December through February (Fig. 2). Peaks and valleys of pCO_2 have been more or less consistent seasonally for the last 30 years (Fig. 3).

High-resolution monitoring

CO_2 concentrations in Kartchner Caverns vary by location and season. CO_2 concentrations and meteorological variables show a complex relationship—neither temperature nor pressure individually drive pCO_2 variability throughout the cave. The entrance sinkhole was the only site monitored during both the warm (July) and cool (February) seasons (Fig. 4). In winter, sinkhole pCO_2 rarely climbed above 1,000 ppm, indicating a fairly stable system in which the cave is either not breathing or breathing in. The cave only breathed out at low atmospheric pressures and/or when winds were stronger than 20 mph. In the summer, pCO_2 in the sinkhole reached levels of 2,500 ppm during conditions of high surface temperatures and low atmospheric pressures. Below surface atmospheric pressures of 101.3 kPa, the CO_2 concentrations at the sinkhole tended to be higher, indicating the cave was exhaling.

Deeper in the cave, at Main Corridor (MC), wind speed demonstrates the strongest impact on CO_2 concentrations (Fig. 5), but atmospheric pressure may also affect cave ventilation. A moisture boundary is observable at the MC site year-round (Fig. 6). This moisture boundary was discovered to also be a “capnocline”, above which pCO_2 is higher and is consistent with the deeper cave sections and below which pCO_2 is more closely related to outside/atmospheric air. The capnocline present at this location has been observed to migrate seasonally (unpublished data, Kartchner Caverns Cave Unit).

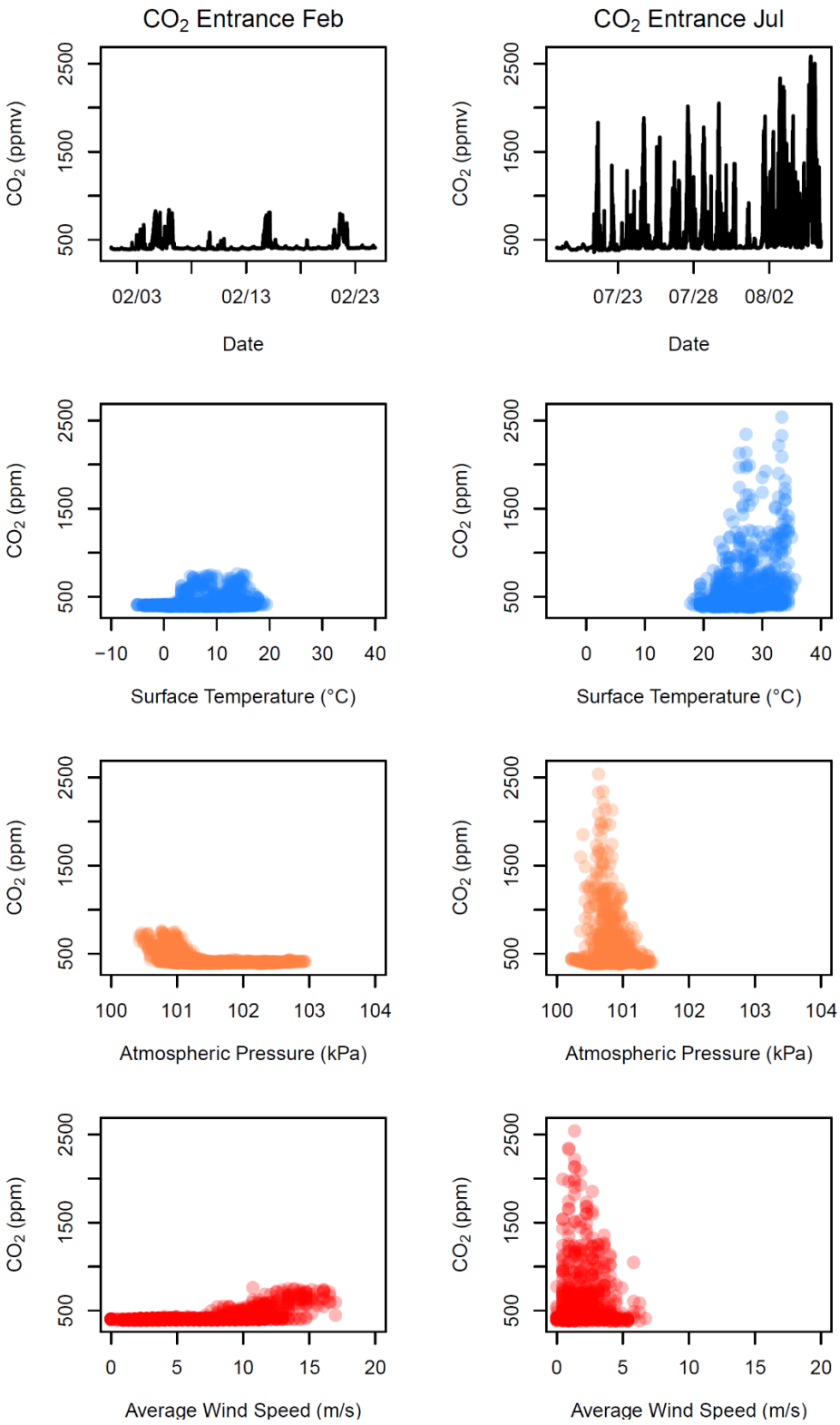

Figure 4. Time series of pCO2 in February and July at the Kartchner Caverns Sinkhole entrance. pCO2 is also compared to surface pressure, temperature, and wind speed.

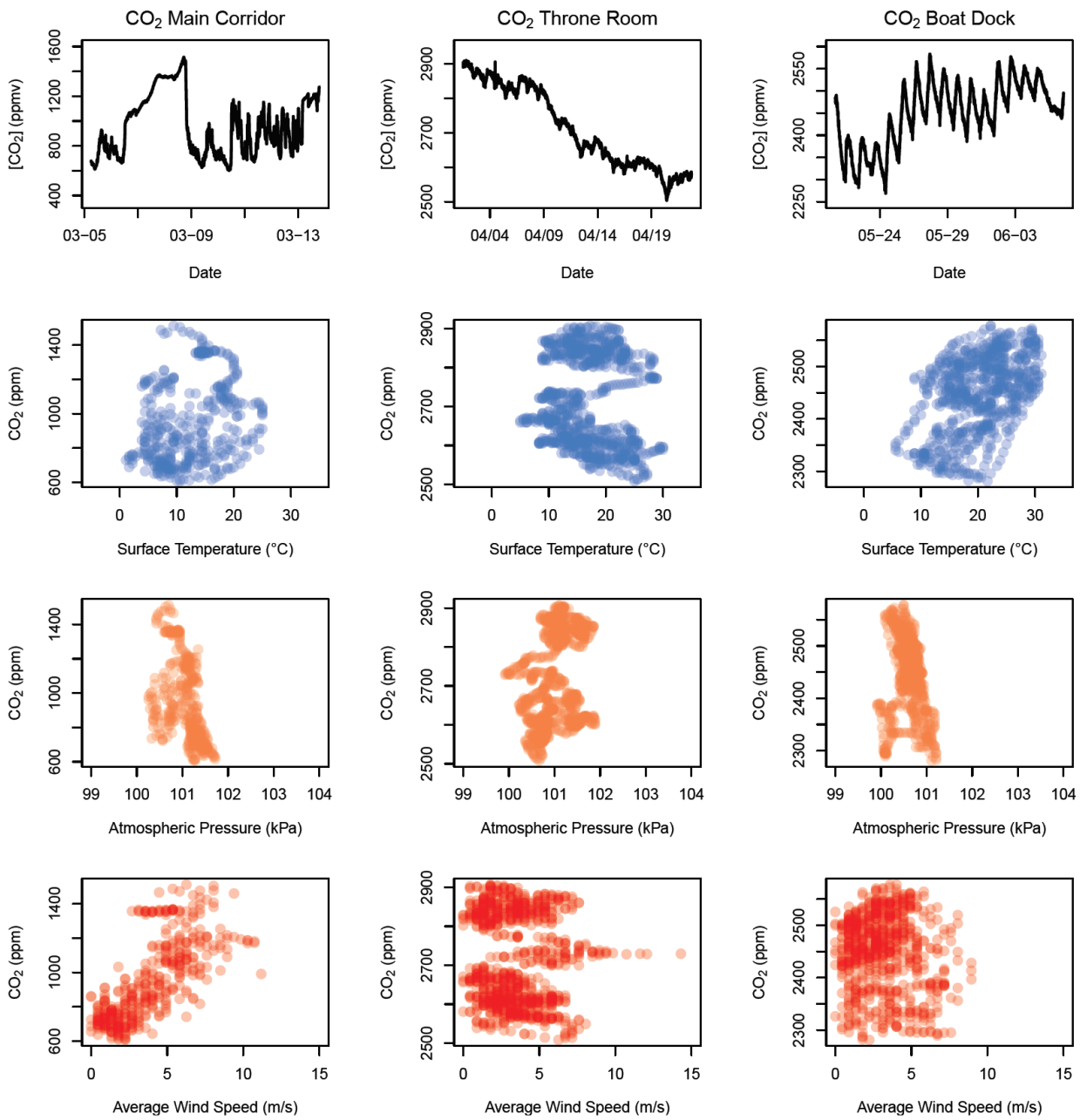

Figure 5. High-resolution time series of pCO2 variability at selected sites throughout Kartchner Caverns. pCO2 is also compared to surface pressure, temperature, and wind speed. Figure 1 shows site locations.

Figure 6. Photograph of CO2 meter above and below the capnocline (CO2 gradient). Below the capnocline, air appears to be drier and pCO2 is lower, more consistent with cool, dry, outside air. Above the capnocline, air is wetter and has a higher concentration, more indicative of cave air (Photos taken in March 2019).

The Boat Dock and Throne Room sites are the furthest from the cave entrance and exhibit the highest pCO_2 values (Fig. 5). Atmospheric pressure and temperature appear to exhibit a relationship to pCO_2 at the Boat Dock, but the Throne Room shows no obvious contemporaneous relationships to any of the three measured variables in the time frame of the study (April).

Discussion

The exchange of air between Kartchner Caverns and the atmosphere depends on several factors including wind speed, air temperature, and atmospheric pressure. These factors vary in importance at each particular site, contrary to popular understanding that temperature and pressure alone govern cave ventilation.

In both the warm and cool seasons, the sinkhole site exhibited high CO_2 concentrations whenever atmospheric pressure dropped below 101.3 kPa. In other words, the cave breathed out high-CO_2 air every time the pressure dropped below 101.3 kPa. This is consistent with the findings of the original baseline studies of a ventilation threshold of ~101 kPa (Buecher, 1999; note a small typo in the original figure mislabeled the y-axis). This suggests that the fundamental controls on cave ventilation have been stable over 30 years and that management practices, modifications, and tourism have not substantially influenced the ventilation regime of the cave.

This study shows that in passages near the entrance, wind may be an important mechanism to initiate cave ventilation. That is, diffusion due to a density gradient alone does not explain pCO_2 variability, and high winds may draw air out of the cave (i.e., a Bernoulli-type effect). Deeper in the cave, at the Throne Room site, however, none of the variables studied appear to drive pCO_2 variability, although lagged relationships, which we would expect given the distance between the Throne Room and the sinkhole, were outside the scope of this study.

Daily pCO_2 cycles at some sites may be due to tourism, e.g., the Boat Dock site, where tourists stand for about 5 minutes out of every 20 minutes on guided tours. However, more data throughout the cave along the tour trail will be needed to quantify the effect of tourism on cave air CO_2 levels.

Some parts of the cave demonstrate pCO_2 stratification. At the MC, the visible moisture boundary (Fig. 6) was also discovered to represent a gradient in CO_2 concentrations. This capnocline represents colder, drier, low-pCO_2 air from outside intruding beneath warm, wet, high-pCO_2 cave air. The position of the capnocline migrates seasonally (Kartchner Caverns Cave Unit, unpublished data). Buecher (1999) expressed the presence of a fog observed “frequently during winter months” that overlaid “cooler, drier air near the floor,” suggesting this boundary has been a consistent feature of the Kartchner Caverns entrance passages at least a handful of times over the last 30 years.

Conclusions

Cave-air CO_2 has been relatively stable over the last 30 years in Kartchner Caverns. High-resolution CO_2 monitoring has allowed for a more detailed understanding of potential variables that affect cave-air carbon dioxide concentrations. Tourism may only affect pCO_2 in some areas of the cave, where guests stand for long periods of time. Wind speed dominates entrance passage cave-air CO_2. Temperature and pressure initiate a density gradient, but wind allows for more rapid CO_2 movement than by diffusion alone, a slightly more nuanced behavior that suggests future study of pCO_2 drivers is warranted in Kartchner Caverns and possibly other

caves. The relatively stable conditions observed over several years of monitoring prior to development and post development suggest that the management practices used at Kartchner Caverns have preserved much, if not all, of the ventilation features present prior to development.

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USING SHOW CAVE LIGHTS AS A CAVE MANAGEMENT AND INTERPRETIVE TOOL

Rodney D. Horrocks[1c]

Lighting systems in show caves can do much more than just facilitate visitation. Cave lights can be used to address multiple cave management issues at the same time that they are used to highlight or reveal cave features. Lights can be used to address public and employee safety, eliminate disability glare, allow two-way traffic, increase ambient light levels to meet OSHA safety standards, reduce lampenflora growth, discourage vandalism, and lower energy consumption. At the same time, lights can be a valuable interpretive tool that allows greater flexibility in how interpreters/guides present a cave to visitors. Individual lights can be turned on to direct visitors' attention to specific natural or cultural features. Light shows, consisting of groups of lights that are turned on in a sequence, can be used to reveal spectacular features or scenes within a cave. The cavern darkness experience can be used to educate visitors about the true nature of caves. Instead of treating the cave like a building interior, cave lights can be designed to preserve the intrinsic nature of caves by utilizing dimly lit or totally dark areas, especially for redundant features or unimpressive areas. Lights can address visual effect and atmosphere by utilizing texture, contrast, color, shadows, and blackness to evoke mystery and beauty. When a new cave lighting system is originally designed or when one is replaced due to age, each of these topics should be addressed to maximize the potential benefits of using lights in a show cave.

Cave lights in show caves can be used to address visual effect and atmosphere by utilizing texture, contrast, color, shadows, and blackness to evoke mystery and beauty as seen in this photo by Peter Jones of the Chinese Theater in the Big Room of Carlsbad Cavern.

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LAVA BEDS NATIONAL MONUMENT: TEST SITE FOR MARS MISSIONS (ON BECOMING THE PROTOTYPE LAVA BEDS INTRAGALACTIC MONUMENT FOR MARS)

Patricia E. Seiser[1c]

How does one test instrumentation to be used in the lava caves of Mars? Why, you come to Lava Beds National Monument, of course. The NASA BRAILLE (Biological and Resource Analog Investigations in Low Light Environments) Team has selected Lava Beds as an analog environment to study, evaluating technology and methods that will be used to look for life or geochemical evidence of life on Mars. The BRAILLE team is characterizing the microbial life in caves, the nutrients in rock and water that feed them, and the biominerals produced by the microbes living there. In addition, they are using the NASA Ames Research Center's test rover, directed by a remote surface team who set up a Mission Command Center at Park Headquarters, to conduct autonomous robotic life-detection and mapping operations in Valentine Cave. These exercises help the team test mission operations concepts that may one day help NASA in planning similar activities for a Mars mission.

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BEST PRACTICES FOR COLLECTION OF PALEOCLIMATE RECORDS FROM ACTIVE SPELEOTHEMS

Andy Armstrong[1c], Brendon Quirk[2]

In August 2016, a research team from the University of Utah and the U.S. National Park Service collected core samples from three speleothems at Timpanogos Cave National Monument in Utah. The cores were retrieved as part of a larger scientific project looking to understand paleoclimate during the Late Pleistocene in the Northern Great Basin. Stalagmites have recently emerged as key continuous, semi-quantitative descriptors of paleohydrology and climate. However, stalagmites are also some of the most important and visible geologic resources in a cave. This is especially true in publicly accessible caves, like Timpanogos Cave, where stalagmites are both geologic features that are preserved and protected for their own sake and also serve as valuable resources for visitor enjoyment. Traditional sampling techniques, which can go as far as the sawing and removal of entire stalagmites, are not attractive options for cave managers who must balance scientific discovery with preservation. The collection of core samples down the growth axis of a stalagmite mitigates resource impact while ideally still providing the most important material for scientific inquiry. In addition to already yielding data about the effects of Lake Bonneville on local paleoclimate, cores from the Timpanogos cave will be preserved for future research. The core sites were restored using new best practice techniques in order to rehabilitate previous aesthetics and microhydrology.

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CAVE RESEARCH WHEN ALL THE CAVES ARE ON PRIVATE LAND

Mike Futrell[1c], Andrea Futrell[1]

The vast majority of caves in the eastern United States are on private lands. Approaching landowners about access to caves on private property for exploration, research, and conservation requires careful planning and thoughtful interactions. Access to a cave is frequently built upon a personal relationship between the cave researcher and the landowner. It is important to have an understanding of the local culture as well as knowledge of cave laws and landowner liability. Consensus building and communication within the caving community is also essential to maintaining access. Owners initially want to know their potential liability and what's in it for them. Some owners are very interested and curious, others not so much, and a few outright hostile. For the long-term, maintaining a relationship by sharing maps, photos, and research findings is key. Working with cave landowners is unusual because it encompasses understanding agricultural and forestry practices, scientific research, ecology, recreational use, and a diverse group of people. Most speleological knowledge in the eastern US is a direct result of landowners allowing access for cave exploration and related research. Quite often a cave owner will be willing to allow a small group access for mapping and research while not allowing recreational caving. This approach can benefit the researcher as well, as it helps to alleviate concerns that sport cavers could jeopardize access. Increased economic development pressure and climate change related concerns make it even more important to work with cave owners toward a further our understanding of natural systems, including those of the subterranean realm.

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VIRGINIA UPDATE ON LINEAR ENERGY PROJECTS CROSSING THE APPALACHIAN KARST: ATLANTIC COAST AND MOUNTAIN VALLEY NATURAL GAS TRANSMISSION PIPELINES

Wil Orndorff[1], Tom Malabad[1], Katarina Kosič Ficco[1]

Introduction

The Mountain Valley (MVP) and Atlantic Coast (ACP) pipelines began construction in early 2018 to transport shale gas from the Appalachian plateau to the Eastern seaboard. Both pipeline corridors cross the Appalachian Ridge and Valley province where exposures of Paleozoic carbonate bedrock host karst (Fig. 1) characterized by extensive and biodiverse caves, sinkholes and sinking streams, and aquifers connected to wells and springs. Orndorff et al. (2017) provides an overview of concerns raised by the Virginia Cave Board, efforts by VDCR to address data gaps, and the extensive environmental assessments pursuant to karst performed for both projects (Draper Aden, 2017a; Draper Aden, 2017b; GeoConcepts, 2018a; GeoConcepts, 2018b).

Progress on both projects has been slowed by legal challenges to permits and other regulatory obstacles. The state of the right-of-way and associated access areas for both projects have been suspended at various stages of construction, ranging from trees cleared, to grubbed and graded with erosion and sediment controls in place, to pipe in the ground with stabilization and revegetation in progress. ACP project co-proponents Dominion Energy and Duke Energy announced the cancellation of the Atlantic Coast Pipeline project on July 5, 2020, citing the legal uncertainties facing the project. On the same day, Dominion announced the sale of all its gas pipeline and storage assets to Berkshire Hathaway and stated that the sale was part of a move toward sustainability focused utility operations.

Between Federal Energy Regulatory Commission (FERC) dockets for Pre-filed National Environmental Policy Act (NEPA) Activities for Proposed Gas Pipelines (code PF) and Certificates for Interstate Natural Gas Pipeline Companies (code CP), for both ACP and MVP the word “karst” has of this writing appeared in over 1,000 of the filed documents (Table 1). A detailed review of these documents is beyond the scope of this article, but interested readers may access them online at the FERC Docket search website: https://elibrary.ferc.gov/eLibrary/search. The degree to which the authors of these documents actually understand karst and associated environmental issues is highly variable, although some are recognized experts in the field (e.g. Kastning, 2016). Karst emerged as one of the central environmental concerns shared by regulators, project proponents, and opposition groups on both of these projects.

This paper is an update on karst-related activities in Virginia pursuant to the two pipelines, including additional data development to support environmental monitoring and response, impacts to karst resources from construction incidents, and shortcomings in karst resource assessment that created or exacerbated these issues.

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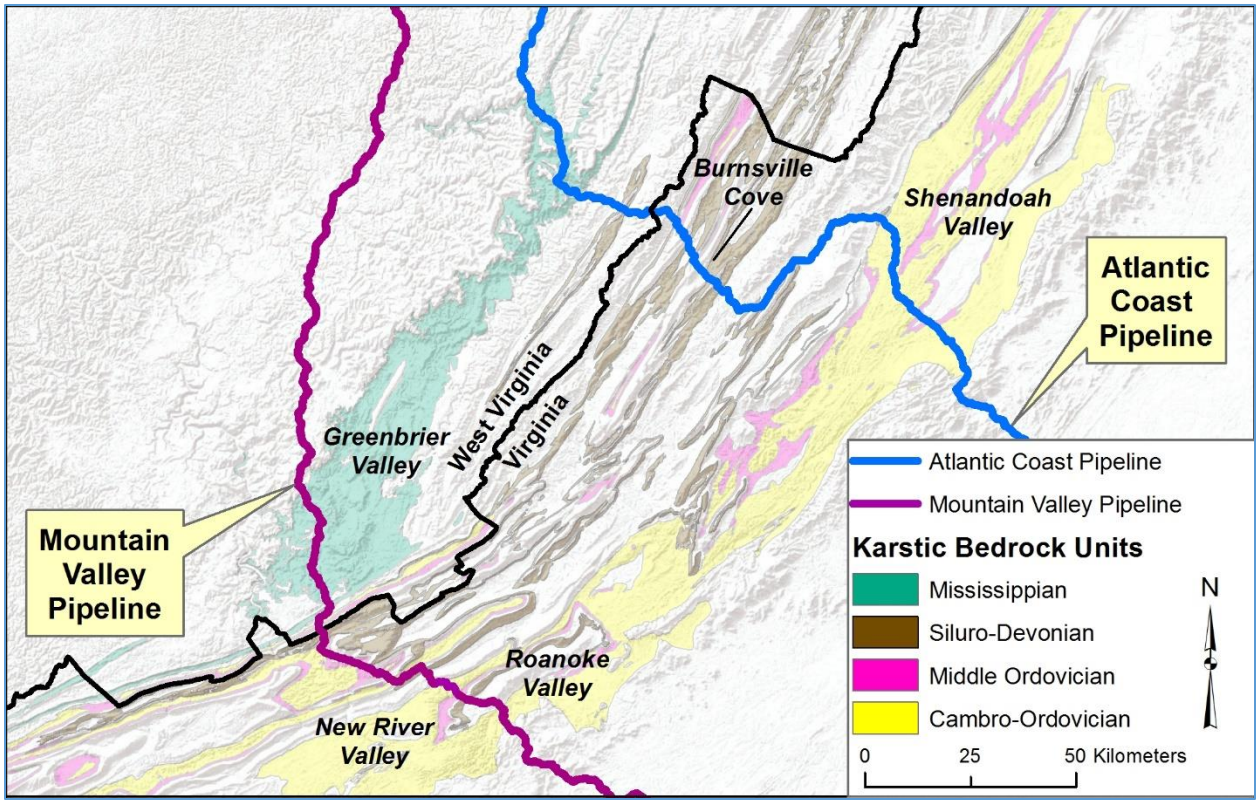

Figure 1. Atlantic Coast Pipeline and Mountain Valley Pipeline Corridors and the Appalachian Karst (Weary and Doctor, 2014).

Table 1. Documents submitted to FERC regarding ACP and MVP containing the word "karst."

Project	Docket	Number of documents including keyword "karst"	From	To
ACP	PF15-6	446	9/16/2014	12/20/2016
ACP	CP15-554	948	8/18/2015	8/3/2020
MVP	PF15-3	574	10/30/2014	10/6/2017
MVP	CP16-10	1,067	10/23/2015	9/25/2020

Additional Data Development

Virginia DCR staff testified at the State Water Control Board hearings in December 2017 pursuant to certification of each project by the Virginia Department of Environmental Quality under Section 401 of the United States Clean Water Act. Additional research to address karst-related data gaps was incorporated into the respective certification documents, which can be viewed at www.deq.virginia.gov/Portals/0/DEQ/Water/Pipelines/MVP_Certification_Final.pdf and www.deq.virginia.gov/Portals/0/DEQ/Water/Pipelines/ACPCertificate122017.pdf. Along the Virginia portion of the ACP route, GeoConcepts Engineering, Inc., now a subsidiary of Terracon, performed dye traces along three sections of the pipeline corridor to determine its relationship to water supplies. In Augusta County, GeoConcepts delineated the sections of the corridor contributing to two springs used by the Augusta County Public Service Authority—Gardner

Spring and Deerfield Spring. GeoConcepts discovered that areas crossed by ACP outside of Gardner Spring's official source water protection area contribute to its recharge (GeoConcepts, 2018c). Pre-construction turbidity monitoring was initiated at a perennial stream crossed by and receiving runoff from the ACP corridor that sinks downstream of the pipeline and flows to Deerfield Spring (GeoConcepts, 2018c). GeoConcepts performed dye tracing in the Little Valley area of Bath County to assess risk to domestic water supplies and to a major, partially thermal spring at Bolar, Virginia (GeoConcepts, 2019). While no connection to Bolar Spring was documented, GeoConcepts documented evidence of complex, variable flow through interlayered limestone and shale strata in the area. This complexity made it impossible to exclude the possibility that domestic water supplies could be impacted were contaminants to be released from the ACP construction area and enter karst features.

Prior to the State Water Control Board hearings, MVP had already contracted directly with VDCR to perform additional dye tracing along portions of the construction corridor crossing karst areas in Giles County. Dye traces were performed from six karst features to determine their resurgence springs in order to facilitate emergency response (e.g. monitoring, spill recovery) should discharge of contaminants from the construction area to karst features occur. Four of these traces are shown in Figure 2 where the MVP corridor runs along an approximately 4-mile long section of karst along the northwest slope of Sinking Creek Mountain. In early iterations of its Karst Hazard Assessment, Draper Aden Associates (2017b) predicted that water entering all karst features in the area would flow to Canoe Cave Spring. However, dye tracing by VDCR showed that most karst features along this section of the corridor actually fed significantly larger, undocumented springs at Steele Acres. In fact, several of the springs shown in Figure 2 were not previously documented. Like many states, Virginia lacks a comprehensive database of springs and even many of the larger springs don't show up on USGS topographic maps. Although Draper Aden's consultants were aware of this problem, under law access to property for resource inventories is provided only in the immediate vicinity of the pipeline construction. This combination results in a situation in that potentially impacted karst aquifers are difficult to characterize. Fortunately, in this case VDCR as a state agency was able to secure landowner permission to identify and monitor these springs. Construction of MVP in Giles County has been held up since late summer 2018 due to several legal challenges and a suspension of permits to work on Forest Service property. VDCR established continuous water quality monitoring stations in December 2019 at both Steele Acres Springs and Canoe Spring to collect background data, especially on turbidity, that may prove useful for evaluating potential impacts to these springs if and when construction resumes.

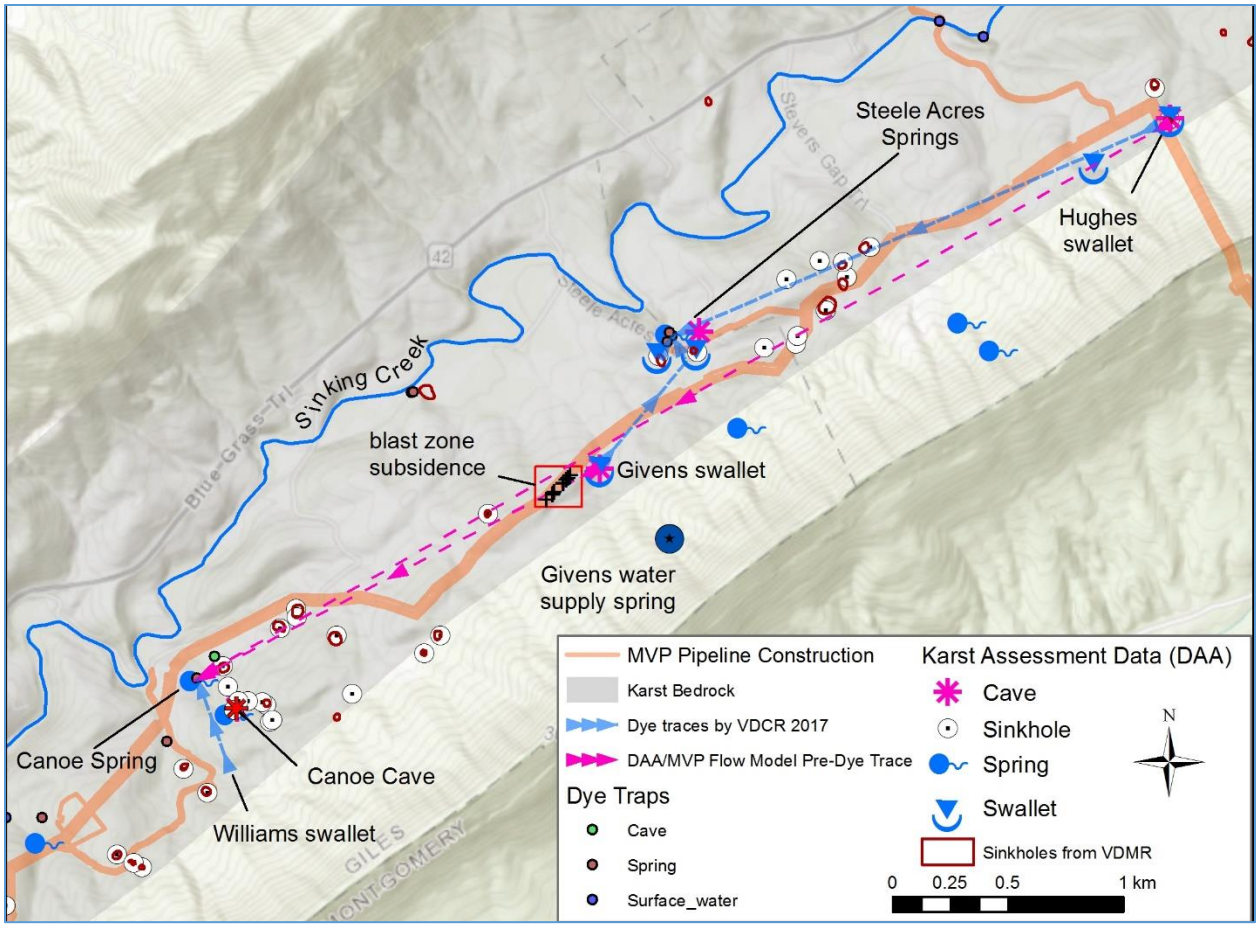

Figure 2. Karst along the north slope of Sinking Creek Mountain, vicinity of MVP Pipeline

Impacts to Karst Resources from Construction Incidents

North Fork Roanoke River Valley: Sedimentation to Sinkholes and a Turbid Spring

Construction of the portion of the MVP pipeline on karst in the North Fork Roanoke River valley was largely completed in 2018 and has subsequently been stabilized and revegetated. However, there were significant documented and potential impacts to karst resources during construction in this area (Fig. 3). The period from May 2018 through April 2019 constituted the wettest year on record across most of western Virginia, including the MVP corridor, exacerbating erosion and sediment management. The combination of steep slopes and frequent high rainfall created flows that overwhelmed the capacity of the erosion control devices (ECDs), although they were, for the most part, installed as specified in approved erosion and sediment control plans (Fig. 4, A and B). Following several significant precipitation events, starting on May 18, 2018, and continuing through the summer, sediment escaped the right-of-way and entered multiple sinkholes at locations shown in Figure 3. While some sediment settled into ponded sinkholes, an undetermined amount entered the underlying karst system (Fig. 5). MVP responded by upgrading its erosion and sediment control devices as shown in Figures 4, C and D. By fall 2018, erosion and sedimentation was largely contained within the construction limits of disturbance. These more substantial and effective erosion control devices are being employed by MVP on karst and other problematic areas of the construction corridor moving forward.

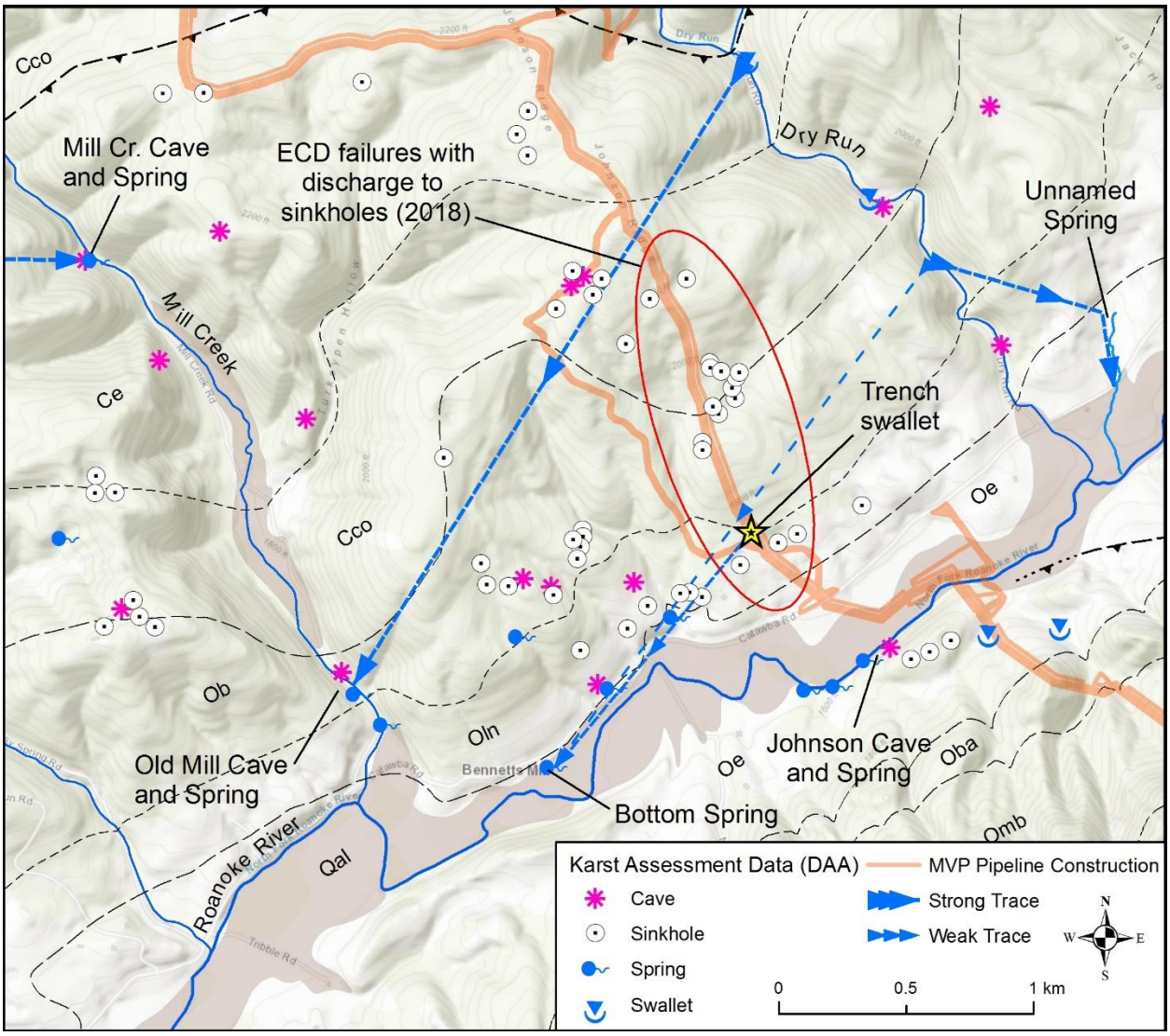

Figure 3. Documented and potential impacts to karst resources of the North Fork Roanoke River Valley from Mountain Valley Pipeline Construction (Karstic bedrock: Cco – Conococheague Formation, Ce – Elbrook Formation, Ob – Beekmantown Formation, Oln – Lincolnshire and New Market limestones, Oe – Edinburg Formation; Non-karstic bedrock: Oba – Bays Sandstone, Omb – Martinburg Formation; Qal – unconsolidated Quaternary alluvial deposits)

Figure 4. Erosion Control Devices (A. P1 silt fence; B. 8" compost sock; C. and D. Sediment sumps, P1 silt fence, triple 8 inch compost sock, and super silt fence).

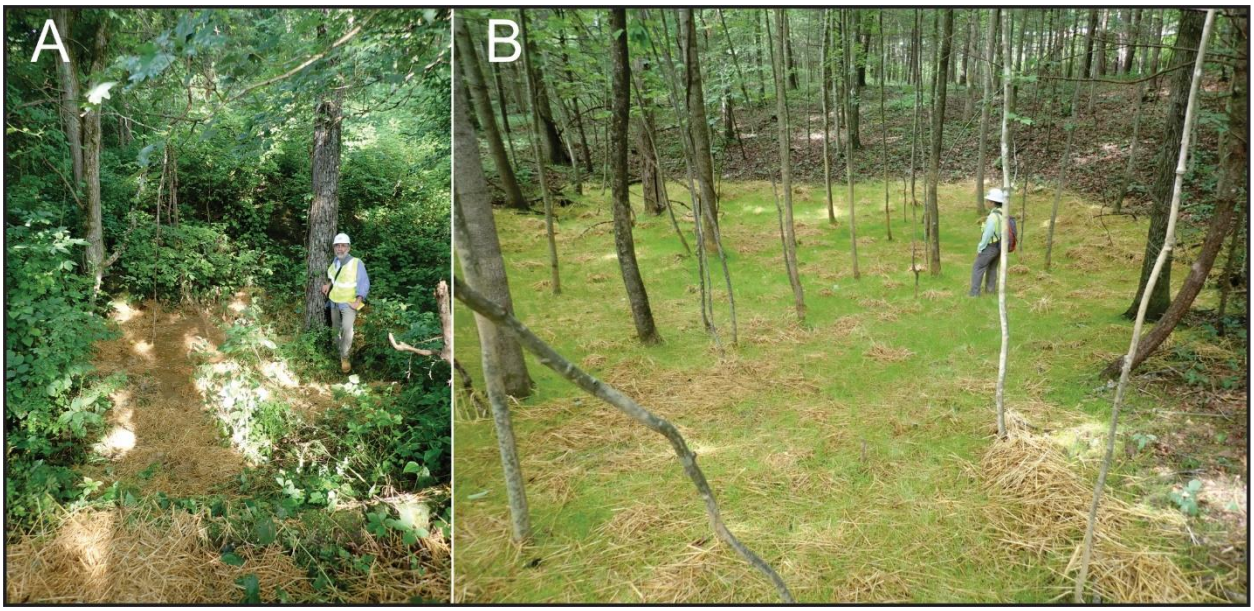

Figure 5. Sinkholes receiving sediment discharged from MVP construction, May 2018 (A. Open throat sinkhole; B. Broad, flat-bottomed sinkhole)

Also following the May 18, 2018, precipitation event, the owners of Bottom Spring (Fig. 3) reported extremely muddy water flowing from the spring (Fig. 6). Similarly, turbid water flowed from Bottom Spring through the summer of 2018, and the owners continued to report high turbidity subsequent to precipitation events at least through September 2020. Based on the result of dye traces performed by VDCR in the early 2000s (Fagan and Orndorff, 2008) as shown in Figure 3, it appeared likely that the source of sediment at Bottom Spring was erosion from the MVP right of way, discharged to sinkholes. In late July, 2018, Draper Aden karst specialists reported observation of a location in the bottom of the recently excavated pipeline trench into which water disappeared during precipitation events. This feature was referred to as the trench swallet. In cooperation with VDCR, dye injected in the trench swallet (Fig. 7) was detected at Bottom Spring as shown in Figure 3. Prior to installation of the pipeline in the trench, a graded inverted filter was installed in the trench in the vicinity of the trench swallet to trap sediment, stabilize the feature, and discourage subsidence.

Figure 6. Muddy water flowing from Bottom Spring, May 2018.

Figure 7. Dye injection into the Trench Swallet, 7/26/2018 (photo courtesy of Mike Futrell, Draper Aden Associates)

In response to the karst impacts of summer 2018, on August 8 a workshop to promote awareness of karst issues associated with pipeline construction was hosted by Draper Aden Associates and included participants from MVP, the Virginia Department of Environmental Quality (VDEQ), and McDonough Bolyard Peck (MBP), erosion and sediment control inspectors contracted by VDEQ. The workshop included field review of some of the features impacted in 2018 and a visit to areas of concern along the Sinking Creek Mountain section of the pipeline (Fig. 2).

In the fall of 2018, the pipeline was installed in the trench in the area shown in Figure 3 and north to Mount Tabor Road, across most of the karst area crossed by MVP in the North Fork Roanoke River watershed. The right-of-way was backfilled and graded by the end of 2018, and subsequently seeded with a mix of annual non-invasive grasses and native plants. Since then, erosion control measures have performed much better, discharges to sinkholes have ceased, and karst-related issues have been limited to a few, small soil pipes and slumps within the right-of-way. By summer 2019 the right-of-way was well-vegetated. Despite these improvements, however, Bottom Spring continues to the time of this report to exhibit high turbidity following significant precipitation. The spring's owners have continued to file regular complaints with regulatory agencies and have sought assistance from their elected state and federal representatives. However, it is difficult to envision that the source of the continued turbidity is

the present MVP construction corridor since it has been reclaimed and stabilized. The owners of the spring contend that the sediment is coming from the trench swallet, but this is unlikely given the installation of the inverted filter combined with crowned fill that sheds water away from the buried pipeline. It may be that the sediment that still appears at Bottom Spring was discharged to sinkholes in the vicinity in the summer of 2018 and/or entered through the trench swallet when open, but which has yet to clear the system and is remobilized during high flow events.

Re-examination of the data from the traces reported by Fagan and Orndorff (2008) leads to an alternative hypothesis. Dye injected in Dry Run and detected at Bottom Spring was also recovered at an unnamed perennial spring to the east of Dry Run (Fig. 3). Dye concentrations in elutant from charcoal receptors at the unnamed spring were well over 100 times higher than from Bottom Spring. Our interpretation in 2008 was that Dry Run sank in two different locations, one carrying water west to Bottom Spring and the other east to the unnamed spring.

However, a second interpretation that could explain both the turbidity and the 2008 dye trace results is that flow from the unnamed spring enters the North Fork Roanoke River, which loses water downstream to a karst conduit that acts as a blind meander cutoff connected to Bottom Spring. Bottom Spring lies in the floodplain of the Roanoke River and flows from alluvial deposits overlying the contact between impermeable shales of the lower Edinburg formation and the underlying Lincolnshire limestone. This contact is a focus in karst conduit development as evidenced by the presence at the same stratigraphic position of the unnamed perennial spring and two intermittent springs between Bottom Spring and the MVP corridor. A meander bend of the Roanoke River comes close to the contact about a kilometer northeast of Bottom Spring and may lose flow to underlying karst conduits, especially during high flow. Turbidity levels in the Roanoke River are generally very high after precipitation events, even upstream of the MVP corridor crossing, due at least in part to bank erosion caused by poor agricultural practices including allowing livestock unrestricted access along much of the river. The turbid water flowing from Bottom Spring may simply come from the river.

This hypothesis would easy to test with a few dye trace experiments. However, this has not been possible yet because of property access issues involving VDEQ, FERC, MVP, and the understandably frustrated owners of Bottom Spring, who continue to insist that the trench swallet is the source of the sediment contamination. The situation underscores the importance of data development prior to construction (and ideally route selection) in two important ways.

First, springs flowing into the North Fork Roanoke River basin in the vicinity of the pipeline were not all even documented and known springs were insufficiently characterized. The connection of Dry Run to the unnamed spring to the east and Bottom Spring, both springs previously undocumented, was the byproduct of a study to determine the source of the stream in nearby Old Mill Cave, designated as significant under the Virginia Cave Protection Act. Dye receptors had been placed at these springs for the primary purpose of dye recovery should it not flow to the significant cave. As such, there was little focus at the time on understanding the details of their hydrology.

Second, once the MVP route had been selected, neither time nor provision for spring inventory and characterization was incorporated into the NEPA Environmental Impact Statement. This criticism applies to the ACP pipeline project as well and may well be a general shortcoming of FERC-regulated interstate utility corridor projects. So when muddy water appeared at Bottom

Spring in May 2018, the only information regulators had was that results from an earlier dye trace suggested some water from parts of the pipeline corridor finds its way to Bottom Spring. This interpretation was reinforced by the trace from the trench swallet, but in no way answers the question as to the source of turbidity. Without background data on the physical and chemical characteristics and flow dynamics of Bottom Spring, it is impossible to say whether the observed turbidity was related to MVP. Access issues further limit our ability to resolve this issue.

Sinking Creek Mountain Karst: Subsidence in Blasted Limestone Area During Suspension of Construction

Construction of the MVP across the karst area along the north slope of Sinking Creek Mountain (Fig. 2) has been suspended since issuance by FERC of a stop work order on August 3, 2018, applying to much of the pipeline corridor. The order resulted from a decision by the 4th U.S. Circuit Court of Appeals in response to a legal challenge filed by the Sierra Club to permits issued by the US Forest Service and the Bureau of Land Management. By this time, MVP had built access roads, cleared and graded the construction right of way, and installed erosion control devices. That summer MVP had begun force assisted excavation (blasting) in some areas in preparation for excavation of the trench.

On February 28, 2019, karst inspectors from Draper Aden Associates discovered and reported several small sinkholes that had formed in the graded construction right of way just west of Givens Swallet (Fig. 2). Initially eight sinkholes were identified over a distance of 120 meters. A ninth sinkhole appeared in 2020 another 30 meters to the southwest. The sinkholes were up to 8 feet wide, 3 feet deep, and more or less circular. Representative examples are shown in Figure 8. Highly fractured limestone bedrock was exposed in some of the sinks, but in others only soil and/or clay residuum. Limestone bedrock on the south, cut-slope edge of the right-of-way exhibits both dissolution and mineral deposition typical of epikarst in the area, forming an irregular bedrock-soil interface consisting of bedrock blocks separated by subvertical joints enlarged by dissolution and filled with soil and clay residuum. Blocks excavated during grading were stockpiled on the north, fill-slope of the right-of-way and also exhibit both dissolution surfaces and mineral deposition. The sinkholes occurred adjacent to the cut slope. Inspection of the site and of construction records revealed that the sinkholes were limited to an area where blasting had occurred in July 2018, but where excavation of the trench had yet to occur.

Pipeline opponents have characterized the features in this area as an “unroofed cave” in complaints filed to FERC (e.g. Bowers, 2019; Bowers, 2020) and expressed concern that the features would compromise pipeline safety. Although karst is well developed in the area, no cave was known in or beneath this immediate area prior to construction, and contractors did not report intersecting cave passage during grading. MVP and its consultants contend that the sinkholes were most likely produced by material raveling into voids created by the blasting process, although a connection to underlying karst voids, some potentially significant, cannot be excluded (MVP, 2019; MVP, 2020). Because the features are small, uniform, and restricted to the blasted area, VDCR karst staff agrees with the conclusion of MVP. Inspection of the area upon excavation will help to determine if pre-existing karst voids played a role in formation of the sinkholes and if such features pose safety or environmental risks to pipeline construction or operation.

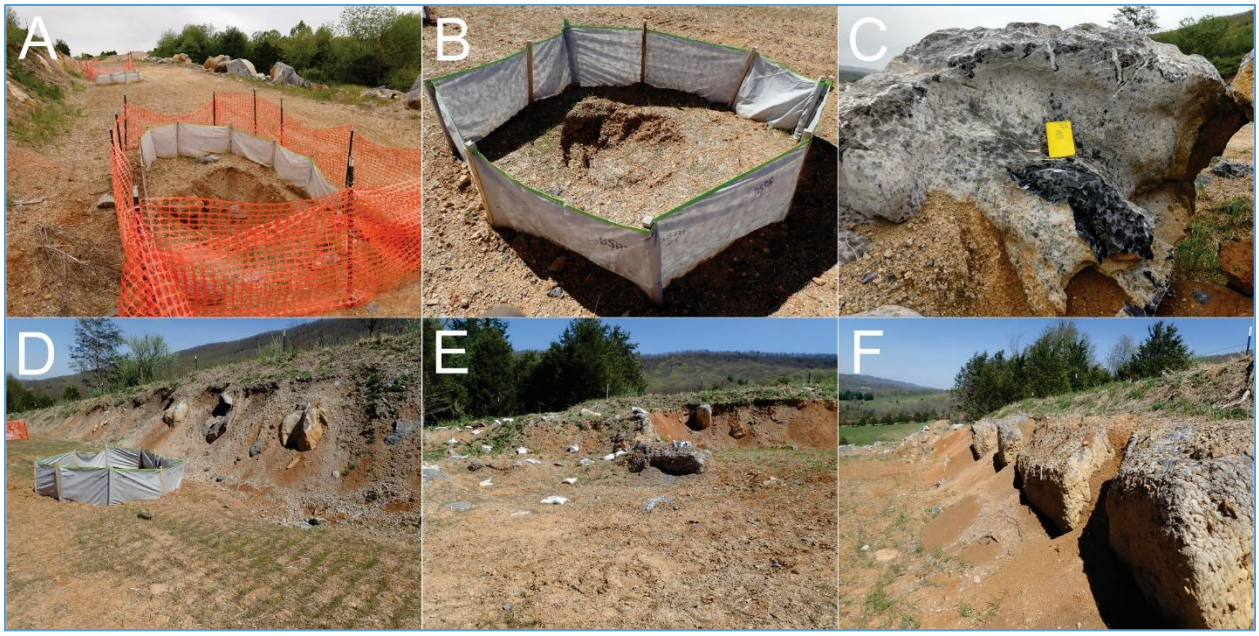

Figure 8. Area of subsidence over area blasted but not excavated, Giles County, Mountain Valley Pipeline, 2019 2020. (A – sinkhole with bedrock exposed, B – sinkhole exposing soil, C – dissolution features on excavated limestone block, D – sinkhole at base of cut slope, E – boundary between blasted and unblasted area, F – epikarst surface

Environmental impacts of MVP construction are locally exacerbated by construction delays as illustrated in this case. Erosion control measures such as silt fence and compost socks, for example, are designed to be temporary and not permanent landscape features. Blasting was supposed to be followed quickly by excavation of the trench and installation of the pipe. However, over 2 years later this still has not occurred. Ideally, legal challenges to permits should be resolved prior to breaking ground on projects such as this to minimize impacts to natural resources and private property resulting from extended project delays.

Shortcomings in Addressing Karst Resources

Major obstacles to karst protection in these projects were 1) the lack of data on karst features, especially springs; 2) the absence of pre-construction monitoring requirements; and 3) inadequate property access to identify and monitor caves and springs remote from the construction area yet potentially vulnerable to impact. These barriers are all part of a larger issue, which is the lack of karst evaluation standards within the regulatory framework of most state and federal agencies.

While ACP has been cancelled, MVP slowly moves forward. As of September 2020, construction of the pipeline as a whole is over 90% complete. However, construction is complete on less than a third of the karst crossed by MVP in Virginia. About 20 miles of the corridor that includes some of the most rugged karst topography has only had trees felled and the right-of-way partially cleared. Hopefully if and when the project moves forward some of the lessons learned in karst along Sinking Creek Mountain and the North Fork of the Roanoke River will help reduce the likelihood of significant impacts to karst resources.

Acknowledgements
VDCR acknowledges the financial support of Mountain Valley Pipeline, LLC; the Cave Conservancy of the Virginias; and the New River Land Trust in performance of water quality monitoring and dye trace studies to delineate groundwater basins in the vicinity of the MVP pipeline.

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NITRATE LOADING IN KARST STREAMS: AN NSF-RET TALE OF COLLABORATION AND STUDENT INVOLVEMENT

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In 2018 and 2019, teachers from a local high school participated in a National Science Foundation (NSF) -funded Research Experience for Teachers hosted at Virginia Tech. Nitrate loading of karst streams was studied by analyzing nitrates in 7 cave streams all located in Southwest Virginia and Northeast Tennessee. In order to determine if land use affects nitrate levels in karst streams, Geographic Information System (GIS) software was utilized to determine the percentage of pastured, forested, and urban land that lies within a 1km radius of sample locations. Nitrate levels in karst streams were found to have a strong positive correlation to percent hay/pasture and a strong negative correlation to percent forested land use. In addition to the research project, an educational unit was developed to expose students to karst issues and to get them actively involved in experiential learning, cave science, and caving. The presentation will highlight the array of benefits of a collaboration between numerous entities from the federal level all the way to local high school students.

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MINIATURIZATION OF TEMPERATURE DATA LOGGER AND ENHANCED RECOVERY TECHNIQUE OF BATS IN HIBERNACULA

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As part of a White-nose syndrome survivorship modelling project, an alternate method of collecting temperatures of hibernating bats was designed and tested using two commercially available products originally marketed for far different applications. The temperature measurements are collected by a small data logger called iButton (https://www.ibuttonlink.com). Without modification these data loggers would be too heavy for the targeted bat species, Little Brown Myotis *(Myotis lucifugus).* The stainless steel case was removed and the circuit board trimmed to shed as much weight as possible. To assist with recovery of the iButton, a Recco reflector (http://www.recco.com) was added. Recco reflectors were originally designed to assist with locating avalanche victims. To the iButtons we attached the company's ultralight version, which is small enough that it can be used to help track insects. At two hibernacula in western Canada the experimental design was tested. One site was an abandoned mine and the other a limestone cave. During a winter visit, bats were removed from their roosting spot, hair on their back trimmed and the iButton/Recco combination secured with veterinary glue. After full arousal, each bat was released to fly. After three months the sites were visited again to recover the temperature data loggers. Visual searches for bats with data loggers (yellow plastic dipped instrumentation) and the use of a Recco specific receiver located varying numbers of bats with loggers. Recovery was better in the cave than the mine where metal debris may have hindered the Recco search. In a cave setting this technique is very promising.

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BUTLER HOLLOW CAVE PROJECT

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The Butler Hollow Project is a five-year project to gate unsafe cave entrances that were part of mining/ore-prospecting projects some decades ago. Bat-friendly gates have been built on twelve cave entrances. Cultural assessment, cave mapping, and biological inventory have been done on all project caves. Additional caves on the Cassville subdistrict, Mark Twain National Forest have also been investigated, mapped, and inventoried as part of a search for more disturbed caves.

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THE MISSOURI CAVE DATABASE

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The Missouri Cave Database is an outgrowth of a 50-year effort by the Missouri Speleological Survey (MSS) to document cave and karst information in the state. The present database was initiated as a small effort in the late 1980's and eventually incorporated thousands of records from the old Cave Catalog, a joint effort between the MSS and Missouri Geologic Survey. Today the database has expanded into a relational database with more than 7500 main table records. Additional descriptions, trip reports, and other materials comprise yet another 17,000+ records. Map records number more than 5500 while biological occurrences in caves comprise over 33,000 records.

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CAVE AND BAT MANAGEMENT ON OZARK NATIONAL SCENIC RIVERWAYS

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The Ozark National Scenic Riverways (National Park Service (NPS)) has over 400 caves within its authorized boundaries. Most of those are on fee-simple land (NPS owned). Active management of the caves involves constant monitoring, bat censuses, biological inventories, mapping, and cave gate building and maintenance. To accomplish this, the NPS partners with and helps to fund park activities of the Cave Research Foundation (CRF), which provides qualified volunteers and part-time professional labor.

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A GEOCHEMICAL COMPARISON OF TWO TELOGENETIC KARST SPRINGS DURING REVERSE FLOW, MAMMOTH CAVE, KENTUCKY

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Previous studies in Mammoth Cave National Park have identified a phenomenon, referred to as *stable reverse flow*, that may significantly contribute to cave formation. Groundwater in the Mammoth Cave Karst Aquifer typically discharges from springs into the Green River, the regional hydrologic base level. When the river stage increases, water from the Green River enters River Styx Spring, flows over the drainage divide, and discharges at Echo River Spring. This study quantified the geochemical and hydrologic changes that occur between the two springs during stable reverse flow. The stage of the Green River, influenced by storm events in the Upper Green River Basin, seasonal changes associated with evapotranspiration, and damming along the Green River, control the timing and duration of stable reverse flows. Data were collected to capture seasonal changes in karst geochemistry, flow rates, groundwater sources, and carbon transport in the karst system. Major ion concentrations, alkalinity, TOC and carbon isotopes were collected weekly; SpC, temperature, and pH were recorded at 10-minute intervals; and pressure transducers were used to collect water levels at two-minute intervals. Data showed the relationships between stable reverse flows, meteorological processes, and human influence on the river basin. Distinct changes in geochemical parameters were used to determine when flow reversals occur. Alkalinity, TOC, and carbon isotope measurements provided information about seasonal and temporal changes in carbon flux, and about how spring flow reversals contribute to carbonate dissolution and conduit development.

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INVENTORYING BROKEN SPELEOTHEMS TO QUANTIFY VISITOR IMPACTS IN CARLSBAD CAVERN, NEW MEXICO

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Broken speleothems are an important indicator of visitor impact. Since 1975, broken speleothem inventories have been conducted in Carlsbad Cavern at irregular intervals, with the last in 1993. In 2019 a systematic method was devised for counting, classifying, and permanently marking breaks within 10 feet of the visitor trail. A total of 11,434 new breaks were identified for the 26-year period between 1993 and 2019, approximately 439 breaks per year. Popcorn breaks composed 65% of all breaks found in 2019. Due to the long time period between counts, it is impossible to correlate breakage patterns with most changes in management. However, the Kings Palace and Scenic Rooms route was designated as a ranger-guided tour in 1992, and there has been a notable decrease in the annual breakage rate from 715/year (1988-1993) to 160/year (2019-1993).

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USING THE BAT CALL DATA RECORDER AS A SMART ALTERNATIVE FOR MONITORING BAT ACTIVITY LEVELS: EXAMPLES FROM SUMMER GRAY BAT (*MYOTIS GRISESCENS*) ROOSTS IN VIRGINIA

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Introduction

The Bat Call Data Recorder (BCDR), designed and manufactured by Tony Messina of Las Vegas, NV, is a low-cost, limited-production device (Fig. 1) that monitors the ultrasonic environment to detect, sample, measure, categorize, and log probable bat call activity. The BCDR measures the low, high, and average sonic frequency and duration of each sample. Samples meeting acoustic criteria consistent with bat calls are accumulated to determine the activity level across user-defined intervals, including the number of events interpreted to represent bat calls and the range in sonic frequency and duration of those events. These data, along with site temperature and battery voltage, are logged at the end of each interval to a text file in fixed-column format, which is easy to import into Microsoft Excel or other analytical software. Use of short user-defined logging intervals facilitates analysis at time scales ranging from a single emergence event to multiple years. Because the BCDR does not record calls, data analysis time is drastically reduced, no specialized software is required, and required instrument memory for a deployment interval remains constant. Though data are not suitable for species determinations, frequencies and durations of calls can provide clues. Minimal BCDR deployment requires additional purchase of an SD card and 12 volt battery. A spare battery and SD card for each installation is recommended, bringing the total cost of hardware to approximately $200 USD. Setup with a 22 amp hour sealed lead acid (SLA) battery allows deployment for 6 to 8 weeks with a 14 hour per day monitoring cycle.

Federally endangered Gray Bats (*Myotis grisescens*) are summer residents in caves and structures across the Upper Tennessee River basin in southwest Virginia, at the northeastern limit of the species range. Summer colonies are believed to be mostly bachelor colonies with only one known maternity colony (Powers et al., 2016; Timpone et al., 2011). Distribution of sites is shown in Figure 2. Extensive banding has shown the majority of Virginia's Gray Bats hibernate in Tennessee, with some tracked as far south as Alabama. Trapping success varied significantly across sampling sites and events described by Powers et al. (2016), suggesting roost occupancy was not consistent and was poorly understood. In addition, climate change and the drastic decrease in Little Brown Bat (*Myotis lucifugus)* populations due to white-nose syndrome (WNS) are factors favorable for the expansion of the range of Gray Bats to the east and north. Establishing a roost site monitoring network is an essential first step to evaluating changes in Gray Bat behavior over time.

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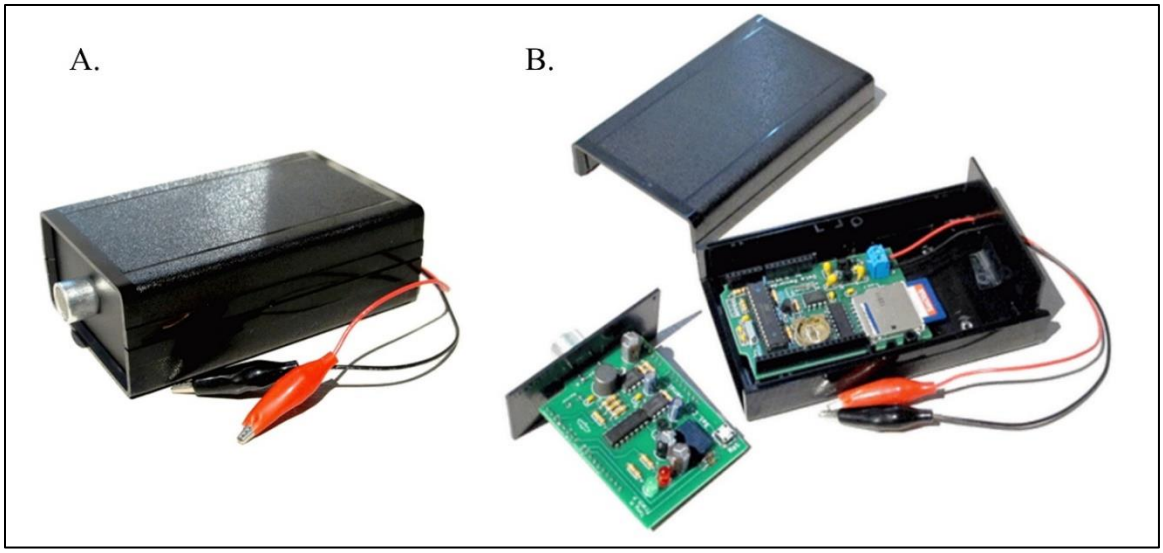

Figure 1. Bat Call Data Recorder. A. Unit as deployed; B. Components. Long dimension is 14 cm.

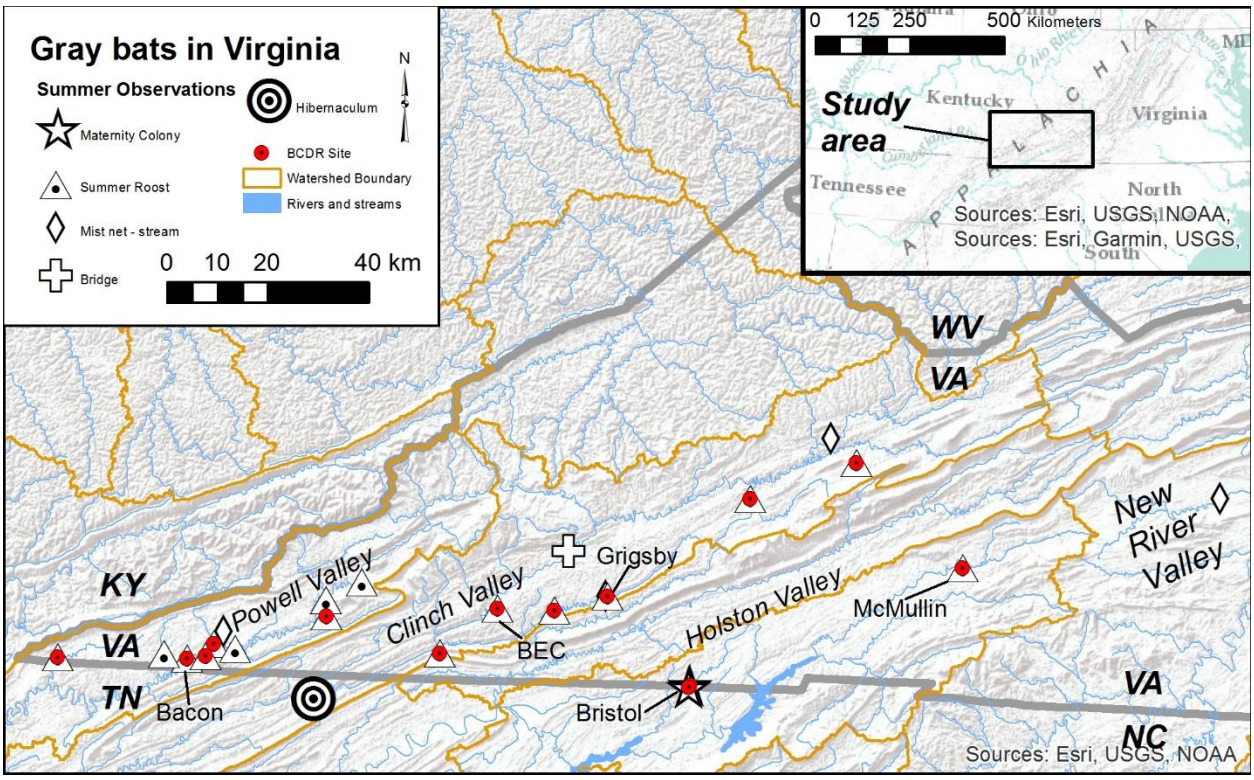

Figure 2. BCDR summer Gray Bat roost monitoring sites in Virginia

Since 2017, VDCR, VDGIF, and Radford University biologists have deployed BCDRs to monitor summer underground roost sites of Gray Bats. These sites comprise an ideal setting for use of the BCDR since they are used almost exclusively by a single species during the study period (Powers et al., 2016).

Materials and Methods

Twelve Bat Call Data Recorders (BCDR) were deployed from early March through early November (Fig. 2) in 2018 and 2019 at 11 underground roosts known to host summer colonies of up to 10,000 Gray Bats. BCDRs were deployed at three of the sites over the same interval in 2017, the pilot project year. All site reported by Powers et al. (2018) are included in the 12 sites. The sites of deployment are:

- Bacon Cave, Lee County, Virginia
- Big Entrance Crawl Cave (BEC), Scott County, Virginia
- Bristol Culvert (two units), Bristol, Virginia and Tennessee
- Copper Creek Spring Cave, Scott County, VA;
- Daugherty Cave, Russell County; Virginia
- Ferrells Cave, Russell County, Virginia
- Grigsby Cave, Scott County, Virginia
- McMullin Cave, Smyth County, Virginia
- Speers Ferry Cave, Scott County, Virginia
- Surgener Cave, Lee County, Virginia
- Young-Fugate Cave, Lee County, Virginia

Monitoring continued in 2020 with the addition of two sites in Lee County, Gibson-Frazier Cave and Litton Cave. Traditionally, all Gray Bat sites in Virginia except Bristol Culvert have been considered “bachelor colonies”. Bristol Culvert hosts Virginia’s only documented Gray Bat maternity colony.

BCDRs were placed between the entrance and primary roost location, within 150 feet of the cave entrance. Microphones were directed toward the flyway. Data logging intervals were set at 10 minutes, and BCDRs were active daily from 1800 through 0800, EDT. BCDR location and orientation at each site was kept constant across the season. SD cards and batteries were replaced every 4 to 8 weeks, depending on battery type. Data text files were imported into Microsoft Excel and compiled for graphical analysis using SigmaPlot 14.

Measured activity levels depend not only on the bat population, but also on site-specific factors including BCDR placement, site geometry, and bat behavior. Nightly values at a site may be expressed as a ratio to the average nightly count for the study period, facilitating comparison across sites.

Results and Discussion

Through the summer of 2020, data coverage has exceeded 90 percent. Most significant data gaps were in the pilot year and at Bristol Culvert during early July 2018. Reasons for data gaps include battery failure (Bristol, 2018), wildlife disturbance (Speers Ferry, 2018), theft (Daugherty, 2019), flooding (Surgener, 2018 and 2019), and lack of access due to high water (Copper Creek Spring Cave, Spring 2018 and 2019).

Data suggest few if any false positives. We had concerns over the potential for false positives resulting from ambient ultrasonic noise from sources including streams, trains, and the urban environment. However, BCDRs did not report significant bat activity at any sites before occupation of roosts in the spring, nor after seasonal abandonment in the fall. Evaluation of false negatives (failure to detect bats when present) was not possible using this dataset.

Through integration of the high-resolution 10-minute data at different time scales, various behavioral patterns became evident. These included seasonal activity patterns across sites, timing of activity within sites, comparison of nightly activity patterns by location and time, and comparison of activity at a site across multiple years.

Seasonal Activity Patterns Across Sites

Figure 3 illustrates the relative activity levels across the 2019 occupancy season at four summer roosts, Bristol Culvert and Bacon, Grigsby, and McMullin Caves. Values are displayed as an activity index (AI), the ratio of total calls per night to average calls per night at that roost over the season. The range of the vertical scale for each site reflects the degree of heterogeneity of activity at the site. Activity at Bristol Culvert was the most consistent, with a peak AI of 3. Variability was higher at Grigsby Cave (AI_{max} ~4) and Bacon Cave (AI_{max} ~5), while the AI_{max} of ~13 at McMullin Cave reflects occasional periods of intense activity interspersed with periods of low and zero activity.

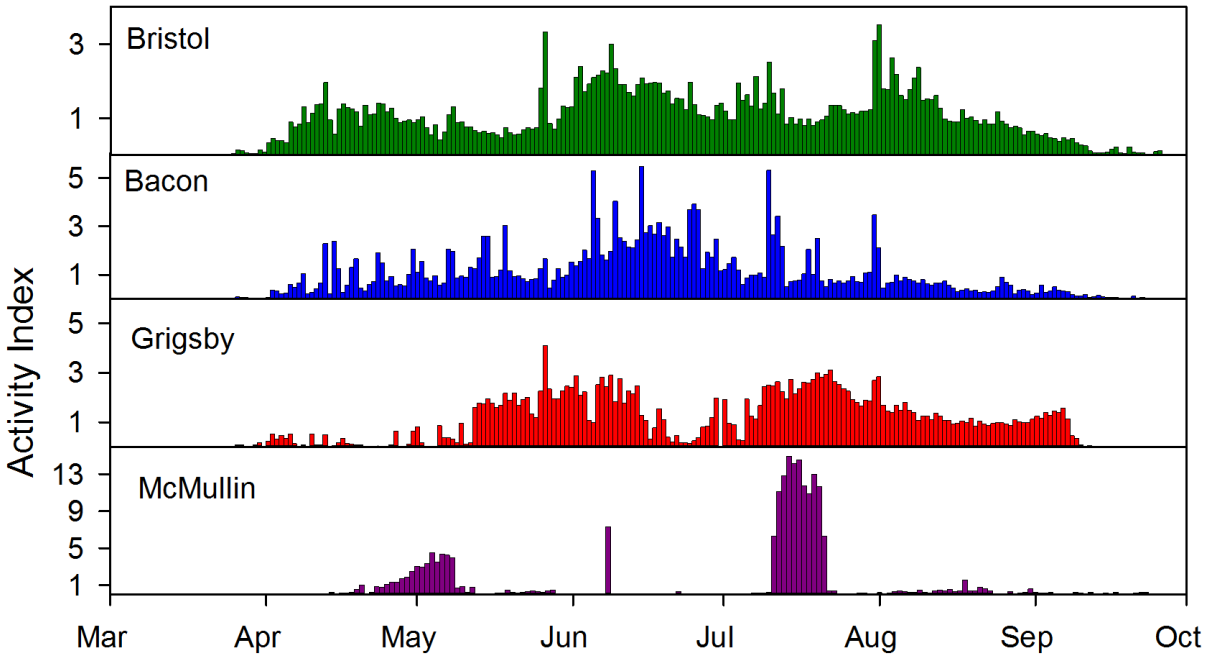

Figure 3. Bat activity at four Gray Bat roost sites in southwestern Virginia, 2019.

Gray Bats arrive in numbers at the roosts in late March through early April, and vacate roosts by late October. Activity and occupancy levels vary significantly across the season. Bristol Culvert is continuously occupied with relatively low, but systematic, changes in activity levels with peaks in late June and late August. Late June peaks are consistent with juveniles reaching volancy (ability to fly), while late August peaks appear to be related to “fall swarm” mating behavior

based on observations of reproductively active adult males and females at the site during this time period in prior years. The mid-July reduction in activity at Bristol Culvert may reflect dispersal of juveniles to other roosts in the region where increases in activity are observed. The Grigsby and Bacon Cave roosts exhibit highly variable activity levels and intermittent occupancy through mid-May, after which occupancy becomes more consistent with higher levels of activity. Bat activity at McMullin Cave remains highly variable across the season, though occupancy is more consistent in August and September, albeit at low activity levels. Gradual changes in activity levels at roosts are more common than abrupt ones, showing that movements of bats between roosts more often occurs as individuals or subgroups rather than entire colonies at once.

Timing of Activity Within Sites

Figure 4 shows the changes in daily timing of activity at Grigsby Cave over the 2018 monitoring season. Data were grouped into emergence (1800–2100), night swarming (2100–0400), and return (0400–0800) categories. When grouped this way, the data showed that not only the level but also the timing of activity at a specific roost site varies significantly over the season. For example, most activity at Grigsby Cave during the peak period of early July was associated with night swarming, suggesting possible visitation by bats not roosting at the site by day. Pre-dawn activity at Grigsby Cave in 2017 spiked in early July and again in early August, and may reflect arrival of new groups of bats to the roost. These data suggest that the ecological function of Gray Bat summer roosts varies over the course of the occupancy season (mid-March through early October).

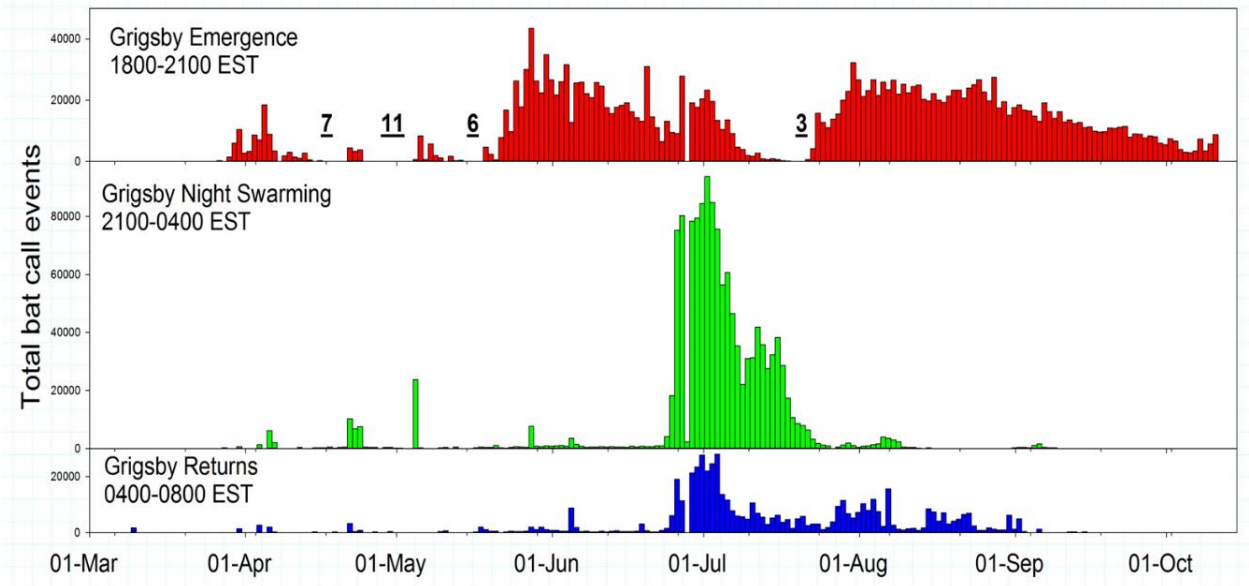

Figure 4. Variations in timing of daily bat activity, Grigsby Cave, 2017.

Comparison of Nightly Activity Patterns by Location and Time

Figure 5 shows representative spring, early summer, and late summer 10-minute activity patterns for three consecutive nights at Bacon, Big Entrance Crawl, and Grigsby Caves in 2018. Activity in spring is dominated by emergence, which is extended at Bacon and Grigsby, but sharp at Big Entrance Crawl. Except for emergence, early season activity levels are very low. In early summer, all sites exhibit peaks in activity just after dusk and before dawn, with an increase in night swarming activity as well, particularly pronounced at Grigsby. The pre-dawn spikes may reflect an influx of bats from another roost site. By late summer, sites exhibit highly concentrated activity during emergence, with consistently low activity the remainder of the night.

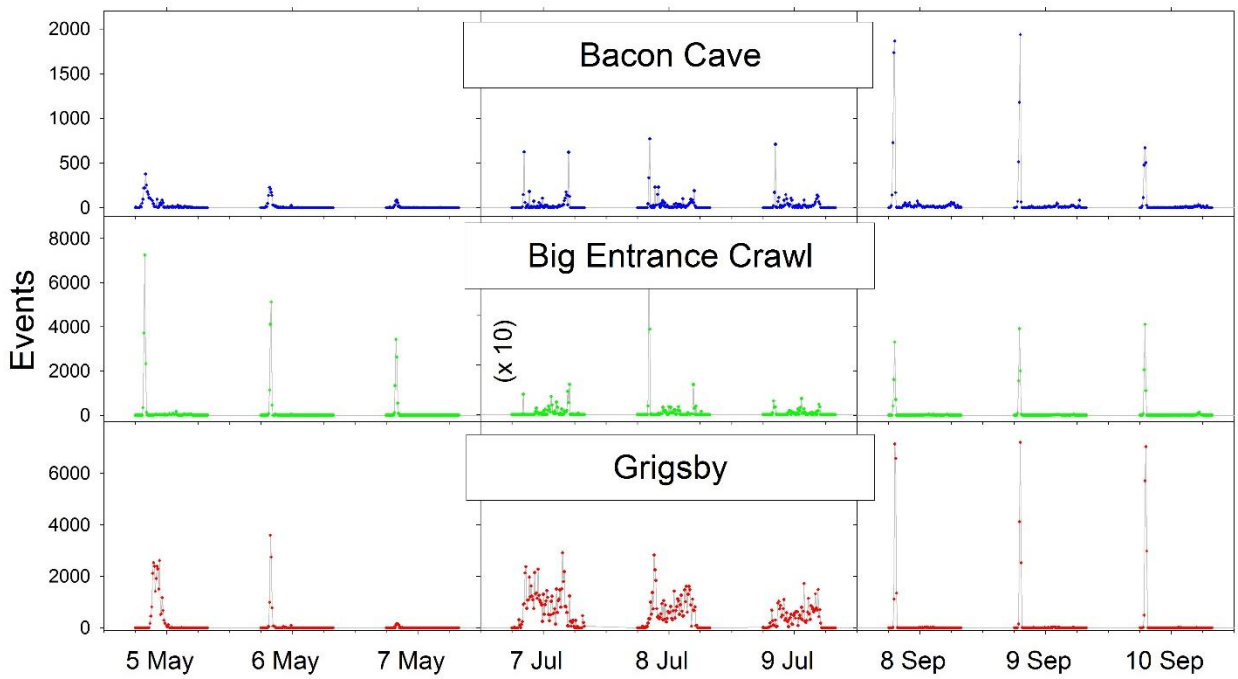

Figure 5. Comparison of nightly bat activity patterns across the occupancy season at three Gray Bat roost sites in southwestern Virginia, 2017.

Comparison of Activity at a Site Across Multiple Years

Figure 6 shows nightly bat activity measure at Bristol Culvert from 2018–2020. The data enable us to see trends that hold as well as variability. In addition, the multi-year dataset allows to some extent compensation for missing data in individual years. Bristol Culvert is continuously occupied by Gray Bats from late March through mid- to late October. Activity levels reach their highest in mid-June through early July, probably reflecting pups reaching volancy. This is followed by a reduction in activity through mid-August, when activity levels pick up again. The timing and degree of this late season increase in activity appears to vary more than the mid-season activity peak. Harp trapping from 2009–2014 at Bristol Culvert resulted in capture of numerous reproductively active adults, suggesting that this late season peak is associated with mating (fall swarm) activity. The reduction in activity from early July through mid-August may reflect dispersal of a significant proportion of juveniles and/or adults from the maternity site. Using BCDR activity patterns to provide a context for results of harp trapping, biometry, exit counts, band recovery, and radio-telemetry is helping us to better understand the complex use of this important roost site.

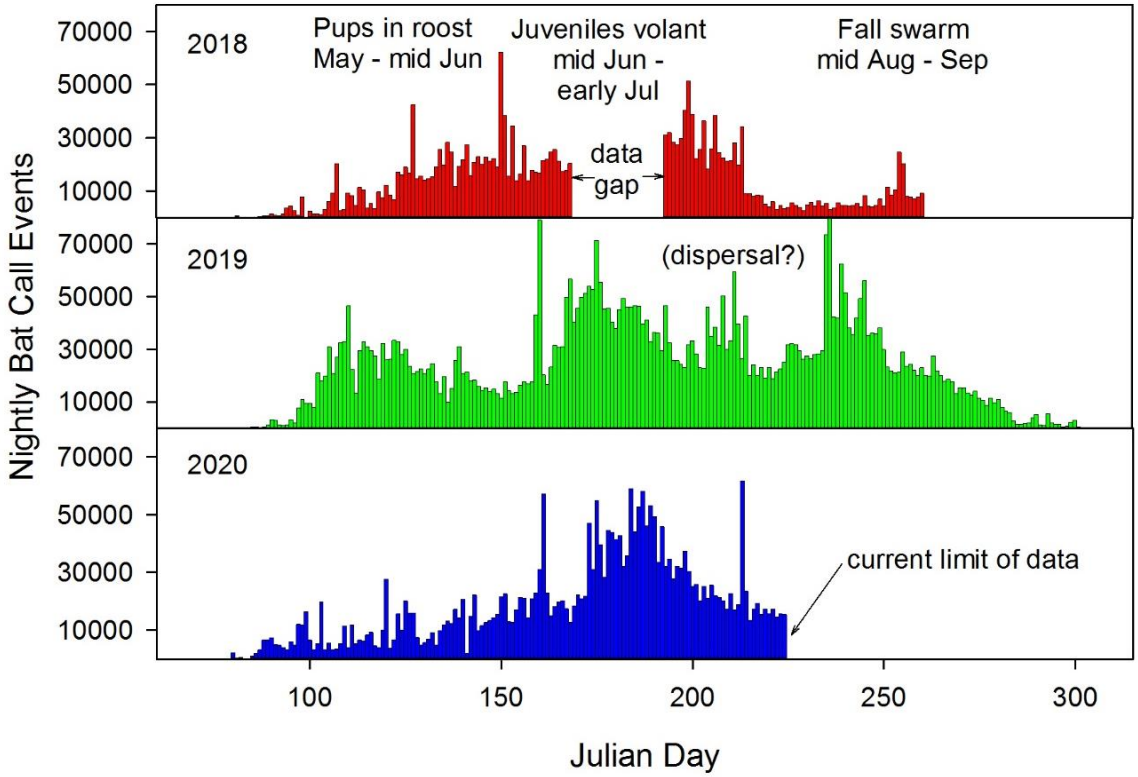

Figure 6. Comparison of bat activity patterns at Bristol Culvert (2018-2020)

Conclusions

The Bat Call Data Recorder is a promising tool for monitoring of monospecific summer bat roosts. Low cost and quick data analysis facilitate monitoring of significantly more roost sites for the same level of effort and cost. The low cost makes damage to or loss of equipment due to factors such as vandalism, animal disturbance, or flooding less of a concern. The resulting high resolution, relatively long-term datasets that cover multiple roost sites are likely to reveal previously undocumented behavioral patterns, as they did in the case of this study.

The patterns of Gray Bat activity we measured at summer roosts in the Upper Tennessee River Basin in southwestern Virginia revealed complex behavior within and between roosts over the course of a season. It is clear that individual Gray Bats use multiple roosts, and that summer habitat protection efforts should be directed at the entire roost network. Other than the maternity colony at Bristol Culvert, it is difficult to rank the relative conservation significance of summer Gray Bat roosts in Virginia. Interpretation of past and future data collected from banding, biometric measurements, exit counts, et cetera should consider these bat activity patterns. Relative timing of peak activity at the maternity site and other summer Gray Bat roosts in southwestern Virginia is consistent with the hypotheses that 1) volant juveniles disperse from the maternity colony to multiple roosts across the region, and 2) behavior at the maternity colony location transitions to mating activity (fall swarm) beginning in late August. Targeted sampling (harp trapping, mist netting) and tracking of individual bats could help test these hypotheses and facilitate a better understanding of summer Gray Bat behavior and ecology.

Additional potential applications of the BDCR apply to multiple bat species, and include measuring fall swarm activity, monitoring hibernacula for winter activity, estimating resident populations based on calibration of BCDR data with quantitative exit counts, and documenting bat activity associated with landscape features or the built environment.

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THE PRESENCE OF PHARMACEUTICALS AND PERSONAL CARE PRODUCTS IN APPALACHIAN KARST WATERS

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In recent years, studies have found that pharmaceuticals and personal care products (PPCPs) are present in surface and groundwater around the globe. The effects of these compounds in aquatic ecosystems are widely unknown. The purpose of this study was to determine the presence of PPCPs in agricultural and urban-impacted karst hydrology. Water samples were collected from karst waters, including cave streams and springs, from across Southwest Virginia and underwent solid phase extraction (SPE) and UPLC-MS/MS analysis. Overall, 40 out of 140 unique compounds were positively identified with each site having between 5 and 23 compounds. Urban-impacted sites demonstrated a higher number of identifiable PPCPs than agriculturally impacted sites. These findings demonstrate a correlation between direct human influence and PPCP presence in karst waters and have significant applications in future karst water quality studies.

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ADDRESSING THE TAXONOMIC IMPEDIMENT: UPDATING THE BIODIVERSITY OF SUBTERRANEAN PSEUDOSCORPIONS IN VIRGINIA

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The study of pseudoscorpions in Virginia's ca. 4000 caves began in 1884 with the publication of the first species endemic to the Commonwealth's caves: *Apochthonius coecus*. Presently 18 troglobiont or troglophilic species have been described from Virginia, with potential for three additional troglobiont species that have been collected but not described. Twelve species are endemic to Virginia with strongly localized distributions, and five species are not endemic but have their type locality within Virginia. An example of the latter is *Hesperochernes mirabilis*, the subterranean pseudoscorpion with the largest known distribution. Efforts began to compile a list of subterranean pseudoscorpions in 1908; the most recent list was published in 2012. A taxonomic impediment has greatly slowed documenting the biodiversity of these enigmatic arachnids. Although specimens potentially representing new species continue to be found, four decades have passed since a new species was described. Here, we summarize the known literature and provide new data we collected in Virginia caves from 2016-2019. We are beginning to address the taxonomic impediment through identifying whether our specimens represent new records of known species or are new to science. Several specimens we have collected show strong promise for being new species endemic to Virginia and will be described in the near future, along with an updated species-level checklist and a taxonomic key. Our results highlight the urgency of developing and maintaining taxonomic expertise and associated professional services to support efforts to conserve the unique subterranean environments of the Appalachian region and beyond.

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HOW MANY RANGERS DOES IT TAKE TO CHANGE A LIGHTBULB? THE SAGA OF UPGRADING AN AGING CAVE LIGHTING SYSTEM

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Kartchner Caverns, located in a state park in Arizona, underwent an upgrade of its 20-year old lighting system in early 2019. When the original lighting was installed, Kartchner Caverns's lighting system was high-tech and advanced, with the goal of making the lights unnoticeable in the cave, quietly fading on and dimming off in the background, with no lights obviously visible to the visitors when avoidable. The entire system was run off of a computer, with each press of a button in the cave changing lights across rooms the size of a football field. Lighting technology has advanced substantially in the last 20 years; bright and responsive LED lighting is now the standard compared to incandescent and halogen bulbs. Kartchner Caverns staff have refrained from upgrading to LEDs, despite the obvious benefits of heat reduction and ability to alter the light spectrum to diminish the growth of algae, because dimming technology was insufficient to capture the original appearance of the tours. Recent events at the cave made it necessary to upgrade, however, and here I discuss the challenges and benefits of our recent upgrade to LEDs and new lighting control system. I will also discuss challenges related to electrical codes in show caves, with the hopes of sparking discussion on the topic more generally. Finally, I will share cave microclimate monitoring data showing the almost immediate impact of upgrading all lights to LEDs.

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