Proceedings of the 20th National Cave & Karst Management Symposium

NCKMS

KARST ELEVATED

OCTOBER 3-7, 2011 MIDWAY, UTAH

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The 2011 National Cave & Karst Symposium in Midway, Utah is now behind us. What an exciting week! I am so glad that you made the trip to the mountains to get Karst Elevated. The week was filled with so many memorable events, from the vertical class off the hotel to the opening social and swim at the Zermatt Resort hot springs, the varied and interesting talks to the field trips to Logan Canyon and Timpanogos Cave. Before I knew it, the week was over.

It is hard to think of the Symposium without feeling grateful for all the support that the organizing committee and I received. The week would have never gone so well without the enthusiastic sponsors that gave money and time to promote and support the NCKMS. There were so many people that were quick to volunteer to make the conference run smoother, set up and clean up, offer rides, and drive field trips. I send a huge thanks to all those who prepared talks, posters, and papers sharing their projects and passions for the underground. And lastly, thanks must be given to the NCKMS Steering Committee for continual support for not only this event, but also their continued efforts toward future forums for cave and karst research.

I hope that the 2011 NCKMS was a wonderful and rewarding experience for you too. I hope you were able to reestablish old friendships and make new ones. I hope you were able to take home some new ideas for projects and programs and put them to use. Can't wait to see you all at the next 2013 NCKMS in Carlsbad, New Mexico!

Cami McKinney

Cami McKinney — Chair NCKMS 2011

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Biodiversity in High-Elevation Caves in Great Basin National Park

By Gretchen M. Baker[1], Steven J. Taylor[2], Margaret A. Horner[1], Jean K. Krejca[3], Michael E. Slay[1], and Benjamin M. Roberts[1]

[1] Great Basin National Park, Baker, NV 89311 USA, 775-234-7331
gretchen_baker@nps.go, margaret_horner@nps.gov, ben_roberts@nps.gov
[2] Illinois Natural History Survey, University of Illinois, Champaign, IL 61820 USA, 217-244-1122
sjtaylor@illinois.edu
[3] Zara Environmental, Manchaca, TX 78652 USA, 512-291-4555
jean@zaraenvironmental.com
[4] Arkansas Field Office, The Nature Conservancy, Little Rock, AR 72205 USA, 501-663-6699
mslay@tnc.org

Introduction

Great Basin National Park contains 43 known caves, including nearly a dozen in subalpine or alpine areas. Little was known about the biota inhabiting them. In 2007, cave biologists and park staff conducted biological surveys in seven high-elevation caves, all above 3000 m. Few cave biota were expected due to the cold temperatures of the caves, their distance from other caves, and limited nutrient inputs.

Methods

Caves were surveyed with two primary methods: pitfall traps and direct survey. Pitfall traps were installed in caves two to seven days prior to a follow-up visit. Traps were baited with limburger cheese with antifreeze at the bottom. Direct surveys targeted the most promising habitat in each cave, with biologists using aspirators, forceps, paintbrush, and other common biological tools to collect biological specimens.

We kept records of biota found for each cave, and within each cave we separated biota by main divisions within the cave, such as entrance, twilight zone, and dark zone. A field identification was given to each specimen. Specimens removed from the cave were generally further identified to a lower taxonomic level.

Results

The seven high-elevation caves had abundant and diverse cave life. The five largest caves (Bristlecone, Broken, Cave 24, Mountain View, and Pine Cone) had between 62 and 126 specimens collected, resulting in a minimum of 12 to 37 taxa. Further taxonomic study could increase those numbers.

Findings included several species endemic to the South Snake Range such as the pseudoscorpion Microcreagris grandis, the millipede Idagona lehmanensis, and the harvestman Cyptobunus ungulatus ungulatus. Additional cave biota found in some of these high-elevation caves included springtails, cave crickets, flies, spiders, mites, and diplurans. These were also found at lower-elevation caves in the park. Some species found in lower-elevation caves, such as the millipede Nevadesmus ophipmontis and the globular springtail Pygmarrhopalites shoshoneiensis were absent from the high-elevation caves. The facultatively trogloxenic butterfly, Milbert's Tortoiseshell Aglais milberti, was recorded in only two high-elevation caves. Some high-elevation caves had a number of unique taxa, largely due to accidentals found at their cave entrances (Taylor et al. 2008).

Discussion

The elevation of the cave did not appear to have a significant correlation with the number of taxa nor the number of unique taxa. The biological complexity found in these high-elevation caves alerted managers to the biodiversity found throughout the park's elevation range. The park plans to conduct additional monitoring of biota and climatic conditions to better understand these cave ecosystems.

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Bigfork High School Cave Invertebrate and Water Chemistry Study

Ernie Cottle
224 Mossy Creek Rd
Bigfork MT, 59911
1(406) 890-1544
ernie.cottle@yahoo.com

Abstract

To develop preliminary information on the natural history and population dynamics of aquatic cave invertebrates in Glacier National Park, students of the Bigfork High School Cave Club conducted a non-collecting, bait box study in four caves. Small Tupperware containers with an entrance hole near the bottom were baited with liver and left in cave pools for 24 hour periods. Afterward, baited invertebrates were counted and returned to pools. Additionally, numbers of non-baited invertebrates were estimated and water chemistry, pool size, and flow rate were measured each time bait boxes were set. In Poia Lake Cave, both planarians (Polycelis?) and amphipods (Stygobromus glacialis) were baited. During the study, from the fall of 2009 to the spring of 2010, amphipod numbers remained nearly constant but their distribution shifted closer to the entrance. Planarian numbers decreased. In Algal Cave, planarians were baited and isopod (Samasellus stygonothryx) numbers were estimated. Also in this cave, the number of both planarians and isopods increased during spring runoff and decreased in late fall. No aquatic invertebrates were observed in the other two caves studied. Based on water chemistry and water flow at bait box sites, it is speculated that planarians are associated with water passing through soil directly over the cave and amphipods are associated with deeper flowing groundwater. Comparing data from this study to a similar one conducted in Algal Cave in 2000, planarian numbers have increased by a factor of 10, isopod numbers have decreased by a factor of 5, and amphipods have disappeared from the cave.

Introduction

In 2009, the Bigfork High School Cave Club began a non-collecting cave invertebrate and water chemistry study in four caves in Glacier National Park(GNP), in Northwestern Montana. The study was designed as a comparison study to two previous studies that were completed by Newell Campbell in 1977 and Paul Hendricks in 1999. The invertebrate study varied from the previous studies in the sense that the club utilized a non collecting method to study the invertebrates in their natural environment. The study ran from September of 2009 until September of 2010.

Objectives

When the Cave Club approached GNP with the intent of conducting the invertebrate study, they had six primary objectives.

Objective 1: Measure hydrological factors that might affect cave invertebrates.

Objective 2: Identify and quantify abiotic factors that might affect cave invertebrates.

Objective 3: Identify and quantify biotic factors that might affect cave invertebrates.
Objective 4: Estimate relative population and distribution of cave invertebrates in each cave without collecting.

Objective 5: Determine seasonal variations of invertebrate population and distribution in each studied cave.

Objective 6: Locate all data on maps of the cave and input data into Geographic Information Systems (GIS) for presentation and analysis.

Methods

As previously stated, the invertebrate study was a non-collective study. The Cave Club invertebrate study was broken down into three major parts:

The caves' invertebrates (which consisted of bait boxes and ocular reconnaissance).
The hydrology of the caves
The water chemistry of the caves.

Invertebrates- Instead of removing invertebrates for lab study, the club would set a 5.0 cm x 5.0 cm bait box which would be baited with 5.0 cc of raw beef liver along the substrate of pools for a period of 24 hours. After 24 hours, the club would return to the site and catalogue any invertebrates found inside the bait box. Any invertebrates outside the bait box were considered as unbaited. To identify the invertebrates, the club brought microscopes into the caves, looked at the invertebrates, and then returned them to their pools. Bait box location criteria consisted of being at least 40 feet apart and were located in separate pools. The ocular reconnaissance was primarily looking at pools and obtaining invertebrate counts at

Algal Cave (12 entries)	Heavy Runner Cave (2 entries)	Poia Lake Cave (6 entries)	Zoo Cave (4 entries)
9/5 and 6/2009	6/25 and 26/2010	9/27 and 28/2009	9/27 and 28/2009
9/15 and 16/2009		6/25 and 26/2010	6/25 and 26/2010
2/19 and 20/2010		9/18 and 19/2010	
8/4 and 5/2010			
11/10 and 11/2011			

Figure 1-1 Detail of data collection from the four different caves in Glacier National Park.

bait box sites.

Hydrology- The cave hydrology portion of the study was to examine flow rates and estimated depth of cave pools over the course of the study. To measure the volume flow rate of a stream section, the volume and velocity of the stream were calculated at specific locations. To calculate the stream volume, the depth of the location was taken in certain cross sections of the stream. To measure velocity, a fishing bobber was attached to a line and permitted to float 1.0 meter downstream; the time it then took to travel that distance was the velocity. The volume was multiplied by the velocity to calculate the volume flow.

Water Chemistry and Temperature- The water chemistry portion of the study utilized different mediums for taking various water chemistry readings. A digital TDS machine (Milwaukee Smart pH/EC/TDS model sm802 meter) was used to measure conductivity, hardness, alkalinity, pH, and dissolved oxygen. Temperature probes were used to measure air and water temperatures. A ChemMets kit was used to determine phosphates. In order to obtain a reading, an ampoule had to be broken in a water sample. Both the sample and the ampoule were removed from the caves in order to prevent contamination. Various test strips measured pH, nitrates, nitrites, total alkalinity, and total hardness, with all tests strips being removed from the cave. As the club completed their study once, they entered their data into a program called ArcGIS.

Data

All of the club's data was entered into mapping software called ArcGIS, as stated in Objective 6. The club scanned both plan and profile views of the cave maps into Adobe Photoshop, where the maps were then altered to work with the GIS program. After the maps were entered, multiple layers were created in GIS with data representing the corresponding invertebrate study data. This program made it easier to represent data for analysis, for example: comparing specific data over the course of the study, and for presentation. This aided in presenting our findings to various GNP officials.

All of the data was collected in four caves, with multiple visits to the caves over the course of one year as seen in Figure 1.

Our data included:

- Counts of planaria, amphipods, isopods, and other invertebrates found in the caves. These three invertebrates were the most common in our study.
- Hydrological readings

Hendrick's pool number	Bigfork HS bait box site	Hendrick's estimated total # of planarians in pool (9/27/1999)	Bigfork HS's estimated total # of planarians in pool (9/16/2009)	Bigfork HS's estimated total # of planarians in pool (2/20/2010)
1	A	0	100	500
2	na	8	not estimated	not estimated
3	B	10	40	4
4	na	20	not estimated	not estimated
5	C	15	0	0
6	D	3	30	2

Figure 2-1 Comparison of the 1999 Hendricks' study and the 2009/2010 Cave Club's study focusing on Planaria in Algal Cave.

Hendrick's pool number	Bigfork HS bait box site	Hendrick's estimated total # of isopods in pool (9/27/1999)	Bigfork HS's estimated total # of isopods in pool (9/16/2009)	Bigfork HS's estimated total # of isopods in pool (2/20/2010)
1	A	60	0	0
2	na	300	not estimated	not estimated
3	B	20	2	2
4	na	300	not estimated	not estimated
5	C	40	0	0
6	D	250	40	50

Figure 2-2 Same comparison as Figure 2-1 but focusing on Isopods in Algal Cave.
There were no amphipods or oligochaete worms found in Algal Cave during the Cave Club's study.

- Water chemistry

Conclusion

In conclusion, the Bigfork High School Cave Club conducted a non-collective, cave-adapted invertebrate study in four caves in Glacier National Park in 2009-2010. The study looked at invertebrates in their natural habitat, rather than studying specimens in the lab. The project compared data collected from two previous studies. The results of the study cannot confidently report aquatic cave invertebrate populations, distributions, or seasonal variations. However, the study can be used as a baseline for future, more extensive research from either the Cave Club or other researchers.

Citations

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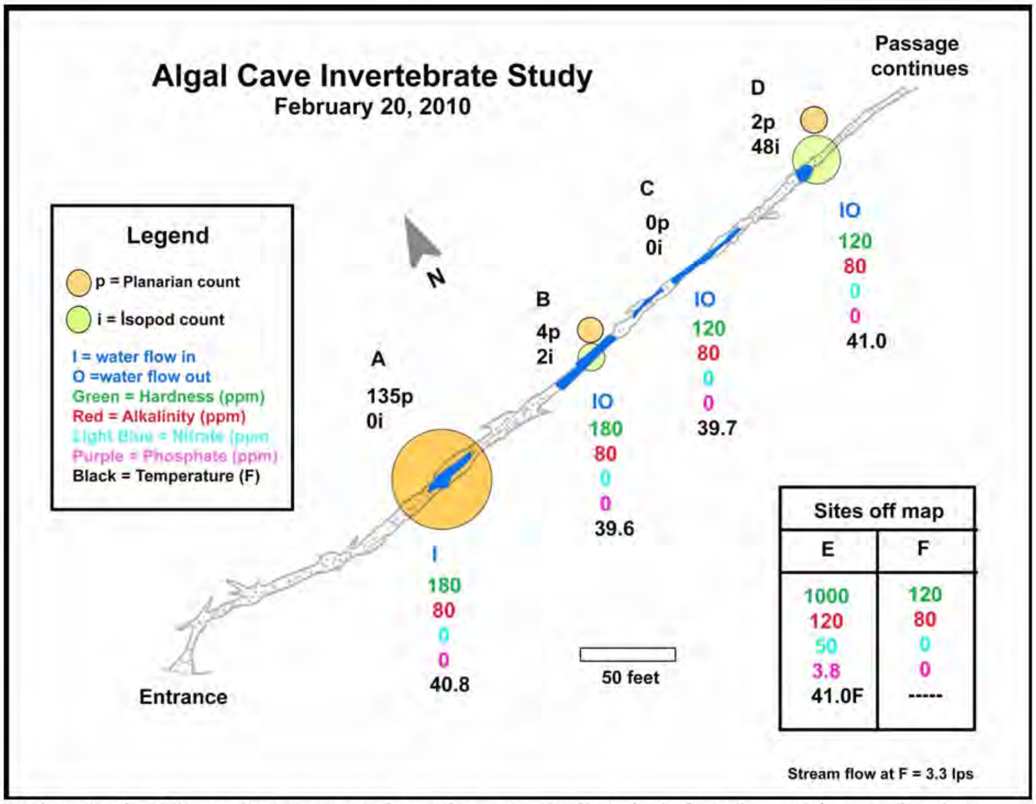

3-1 Sample of a GIS map that represents invertebrate counts, hydrological readings, and water chemistry readings for a research trip to Algal Cave.

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A Long-Term Strategy for Monitoring Biotic and Abiotic Parameters in Caves of the Klamath Region

Jean K. Krejca
Zara Environmental LLC

Sean Mohren
Klamath Network-National Park Service

Daniel Sarr
Klamath Network-National Park Service

Shawn Thomas
Lava Beds National Monument, National Park Service

Abstract

In 2005, the parks of the Klamath Network (KLMN) selected cave entrance communities and cave environments as two of their top 10 vital signs during phase II of their Inventory and Monitoring (I&M) Program. From 2008 to 2011, a team of cave scientists, researchers, statisticians, regional biologists, and monitoring specialists created a plan to measure eight parameters at 31 caves that would help track changes in cave environments due to visitation and associated uses. The four abiotic parameters the team chose were meteorology (temperature and humidity data loggers), water levels (staff gauges), ice volume (surveys from fixed points, photo stations), and human visitation (ticket sales, infrared counters, visitor logs). The four biotic parameters were vegetation (line transects), bats (winter counts), scat and organics (timed area searches), and invertebrates (bait stations). Field crews vetted the measurement techniques in a pilot study of over 20 caves at Lava Beds National Monument and Oregon Caves National Monument, and biologists tested for statistical power using two of the pilot datasets (climate and bats). Standard Operating Procedures detail each of these methods, and include quality control/quality assurance measures, training, data management, and reporting. The details of this project, which are documented in a monitoring protocol, are designed to make these data collection and syntheses efforts outlive changes in park staff and technology. This project met the goal of creating a financially supported monitoring protocol with anticipated results that will help direct management of park resources, public interpretation, and scientific research.

Ongoing Conservation Efforts to Protect the Foushee Cavesnail, Amnicola cora (Hydrobiidae)

Michael E. Slay
Arkansas Field Office, The Nature Conservancy
601 North University Avenue, Little Rock, AR 72205 USA
mslay@tnc.org
(479) 973-9110

Steven J. Taylor
Illinois Natural History Survey, University of Illinois at Urbana-Champaign
1816 South Oak Street, Champaign, IL 61820 USA

Abstract

The Foushee cavesnail, Amnicola cora Hubricht 1979 (Gastropoda: Neotaenioglossa: Hydrobiidae), is a single-site endemic stygobiont found in Foushee Cave, Independence Co., Arkansas. Because little information was available concerning this species, a project was initiated in 2007 to establish baseline data on habitat use and population size. Sampling trips occurred during late spring and summer months to minimize disturbance to hibernating gray bats (Myotis griscesens) and at monthly intervals to minimize in-stream trampling of cavesnails. We established 25 sampling locations along the first ~1,000 m of cave stream and counted snails that occurred within a 0.05 m2 quadrat placed haphazardly at each location. To characterize habitat use, we quantified snail position on substrate and measured water depth, flow, and substrate proportions. Sampling occurred during 3 visits in 2007 and 3 visits in 2011. The quadrat census project spurred additional conservation efforts by several Arkansas state agencies. The potential for groundwater impacts to the cave system was assessed with funding from Arkansas Game and Fish Commission, and this funding was used to delineate the recharge boundary, characterize vulnerability, and document point hazards. Following the recharge delineation, a landowner parcel assessment was conducted to determine number and size of parcels that overlay the cave system. This information was then used by Arkansas Natural Heritage Commission to identify landowners interested in selling property and several land acquisitions are now in progress. Following these acquisitions, over 80% of land recharging groundwater to Foushee Cave will be part of a new Arkansas state natural area.

Characterization of Cave-Inhabiting Arthropods of Puerto Rico: Potential Tools for Conservation

Miriam Toro Rosario, Elvira Meléndez Ackerman
1(787) 300.0602
mtierrapr@gmail.com / tororosa@msu.edu

Poster only

This research gathered baseline data on arthropod diversity, abundance, and environmental characteristics of four caves with varying human use. These caves located in North Karst Belt of Puerto Rico were surveyed in October 2009 (rainy season) and April 2010 (dry season) for soil arthropods. Within each cave visibility, temperature, and relative humidity were measured in three zones delimited by light quality (entrance, twilight, and dark). These zones were significantly different in their visibility estimates but not necessarily in terms of their temperature or relative humidity. Overall, within cave temperature showed a negative (but weak) correlation with relative humidity. Temperature was only positively correlated with arthropod diversity but the role of temperature on abundance could be discarded given that diversity and abundance were highly correlated. More species were captured at rainy season survey, but these tendencies were not consistent with temperature or relative humidity differences between censuses. Our pooled samples yielded 5,922 soil cave specimens that included 41 morphospecies distributed among 17 orders. Hemiptera (67%), Acari (48%), and Isopoda (6.6%) were the most dominant orders in all caves. The dominance of Hemiptera at these cave systems is a departure from what has been reported in well-studied caves elsewhere. Given the potential links between temperature and cave biota future studies should explore the use of cave biota as potential indicators of change in cave systems and in particular how these may respond to expected increases in climate in the Caribbean region.

Population Monitoring of Illinois' State Endangered Enigmatic Cavesnail (Hydrobiidae)

Steven J. Taylor, Robert G. Weck, Marlis R. Douglas, Jeremy S. Tiemann, and Christopher A. Phillips
Illinois Natural History Survey, University of Illinois, 1816 S. Oak St., Champaign, IL 61820
22016 Stemler Rd., Columbia, IL 62236

Abstract

The Enigmatic Cavesnail, Fontigens antroecetes Hubricht (Gastropoda: Hydrobiidae) is known from only a single site in Illinois, Stemler Cave (St. Clair County). Other populations current identified as belonging to this species occur in Missouri. We initiated population monitoring in September 2009, and this monitoring continues through the present. We present findings thus far on snail densities and substrate preferences as determined by our sampling. We have also surveyed other sites in Missouri and Illinois to establish occupancy rates. No additional populations have been found in Illinois, and material from Missouri was confirmed at least to the generic level, with some material collected for comparative molecular analyses. The snail is threatened by declines in water quality, which likely are associated with changing land use practices accompanying urban sprawl in the greater St. Louis metropolitan area. The Enigmatic Cavesnail receives some protection in Illinois, both as a state-endangered species and because its range overlaps with that of the Illinois Cave Amphipod, federally listed as endangered. Within the drainage basin of Stemler Cave, the Illinois Department of Natural Resources, Illinois Nature Preserves Commission, and a variety of private groups, have been working to acquire natural areas upstream of the cave to help protect watershed integrity. Long-term protection of this species will require acquisition of better scientific data as well as vigilant and thoughtful land management.

Assessing Impacts to Endangered Karst Invertebrates in Central Texas

Cyndee A. Watson
U.S. Fish and Wildlife Service
Austin Ecological Services Office
Cyndee_Watson@fws.gov

Poster only

Sixteen species of karst invertebrates are listed as federally endangered species (including spiders, beetles, and pseudoscorpions) in Central Texas. Assessing impacts to these species is a particularly challenging endeavor considering their cryptic nature and low detection probabilities. The Service (U.S. Fish and Wildlife Service) is incorporating the limited life history information on these species into an assessment tool that will help determine likely impacts from project activities, for example, construction near or in cave and karst areas. It also provides suggestions and conservation measures to avoid or minimize those impacts. This tool is being developed by Service employees with knowledge on these species and will allow project proponents direct access to these data when a Service biologist may be unavailable. While this tool will provide useful information to project proponents, it can also help determine whether consultation with the Service should ensue. For example, if by using this tool it becomes apparent that activities from a project will harm or harass an endangered karst invertebrate, then the Service should be contacted. By providing this information in a readily available format, we believe that this tool will assist in preserving more karst areas and provide consistency in how impacts are being avoided, minimized, and mitigated.

White-Nose Syndrome and the Ivory Billed Woodpecker

Tom Aley
Ozark Underground Laboratory
1572 Aley Lane
Protem, MO 65733
417-785-4289
Taley@ozarkundergroundlab.com

Abstract

A few years ago the U.S. Fish and Wildlife Service (USFWS) announced the discovery of a living Ivory Billed Woodpecker in Arkansas. This species had long been considered extinct. It was truly an extraordinary claim and made national news. It also shifted substantial funds from efforts to protect various species on the brink of extinction into Arkansas activities. Unfortunately, it was not true. It was the result of inadequate science and over-zealous agency management rushing to promote their mission and enhance budgets.

With the woodpecker episode in mind, reviewing the scientific credibility of agency responses relative to White-Nose Syndrome (WNS) is appropriate since some rather extraordinary claims have once again been made. Four specific agency positions are considered; they are:

1. That closure of caves on public lands will reduce or prevent the spread of WNS.
2. That WNS is spread, or is likely to be spread, by cavers or cave visitors.
3. That the only bat habitats that warrant management for WNS are caves and underground mines.
4. That it is appropriate to manage most or all caves on public lands as bat habitats to the exclusion of the many other uses and resources that caves provide.

The National Environmental Policy Act (NEPA) requires the preparation of Environmental Impact Statements for federal actions affecting the environment. Federal agencies have adopted unprecedented cave closure actions on the premises that: 1) they are necessary to prevent or slow the spread of WNS, and 2) cave visitors can spread WNS to other caves. Given these rules and premises, any WNS research that involves entry into bat colony areas in caves clearly requires the preparation of an environmental impact statement (EIS) by the agency with management responsibility or the federal agency providing the funding. This is especially true for studies that involved the handling and release of bats, particularly if multiple caves are involved in the studies. The NEPA requirements have been ignored. What the federal agencies have done in their rule-making zeal is create an unavoidable regulatory snare that will delay, or perhaps prevent, the very kinds of research that could benefit the bats in their struggle against WNS.

The Woodpecker Episode

A few years ago there was a flurry of publicity from the USFWS about the discovery of a living Ivory Billed Woodpecker in an eastern Arkansas swamp. This species had long been considered extinct. The reported discovery (touted in agency press releases) made national news and resulted in the shifting of substantial funds from efforts to protect various species on the brink of extinction into buying land and other activities in eastern Arkansas. The basis of the report was limited poor-quality video of a woodpecker flying through a swamp forest. The images, at least on television, seemed hardly diagnostic. Some of us wondered if it was simply a misidentified Pileated Woodpecker, a species far from extinct.

Not heard anything recently about the Ivory Billed Woodpecker being alive in an Arkansas swamp? Oops, inadequate science and over-zealous agency management rushing to promote their mission and realign or enhance budgets. I saw no counter-balancing public relations announcements of the agency's erroneous rush to judgment and stampede into management. At a minimum, good science and responsible agency conduct would have required much better scientific evidence for such an unlikely event as this reported discovery and such a major public relations effort and management response. Offit (2011) in his article "Junk science isn't a victimless crime" quoted Carl Sagan as once writing that "extraordinary claims should be backed by extraordinary evidence". The questionable woodpecker video clearly failed Sagan's test.

A lesson reinforced by the woodpecker episode is that natural resource management agencies too often make decisions based upon opportunities for publicity, inadequate data, and wishful thinking. Agencies and upwardly mobile bureaucrats feel pressures to demonstrate that they are being highly responsive and fulfilling their missions. Additionally, there is an almost overwhelming desire among agencies to enhance their budgets. These pressures do not justify the frequent lack of science-based management too often encountered in both state and federal natural resource management agencies.

Background on WNS

White Nose Syndrome (WNS) is a serious disease that has killed large numbers of bats in the northeastern United States during the last six years. The syndrome is associated with a fungus identified as *Geomyces destructans.* Although some limited and unpublished research suggests that WNS is probably caused by this fungus, this causal link is as yet only tentative and has not passed the rigor expected of scientific findings. Also, it is not known whether the fungus is pathogenic or opportunistic. If this is an opportunistic fungus it may be associated with bat mortality only under certain conditions. For example, an opportunistic fungus might only be associated with bat mortalities when bats were weakened by a disease independent of the fungus. If so, efforts to limit the spread of WNS by limiting the spread of the fungus may be of little or no benefit.

WNS is known to be transmitted bat-to-bat, and the pattern of WNS spread is consistent with transport primarily or exclusively by bats. In addition to the extensive (and in some species very long distance) migrations of bats, there are many documented cases of bats being unintentionally transported long distances and then escaping into new areas (Constantine 2003). Human-aided bat transport could readily explain transport of *G. destructans* into the U.S. from abroad if in fact the fungus is not native to the U.S. It could also explain the discovery of *G. destructans* on bats at locations remote from previously known sites. The transport of WNS via bats is a much more likely mechanism than transport by cavers, yet this bat-to-bat mechanism has been largely dismissed by those intent on blaming the spread of the disease on human actions. While human activity is a root cause for many environmental problems, the emergence or discovery of a new problem does not indicate, let alone prove, causation by people.

It is potentially significant that the fungus *G. destructans* has been found on bats in western Tennessee, Indiana, Missouri, and northwestern Oklahoma yet it has not been associated with any WNS outbreaks in these areas and the extent of the fungal damage to the bats has apparently been relatively minor. Among the potential explanations are:

- An absence of a cause and effect relationship between the fungus and WNS, at least in areas outside the significantly impacted area extending from roughly Virginia into New England.
- Massive mortalities from WNS do not occur until conditions other than the mere presence of the fungus are met. It is possible that WNS has been killing small numbers of bats for a long time but such deaths were not noted until more massive mortalities occurred.

Credibility of Agency Responses

With the woodpecker episode in mind, reviewing the technical credibility of agency responses relative to WNS is appropriate and desirable. The primary federal agencies involved are the U.S. Fish and Wildlife Service, U.S. Forest Service, and National Park Service. I will consider four premises (either stated or implicit) underlying agency policies:

1. That closure of caves on public lands will prevent or reduce the spread of WNS.
2. That WNS is spread, or is likely to be spread, by people visiting caves even if there is no direct contact with bats.
3. That the only bat habitats that warrant management for WNS are caves and abandoned underground mines.
4. That it is appropriate to manage most or all caves on public lands as bat habitats to the exclusion of the many other uses and resources that the caves provide.

The extent to which individual agencies have promoted or embraced the four premises has varied as has the forcefulness of individual agencies in promoting the individual premises.

Will Closure of Caves on Public Lands Reduce or Prevent the Spread of WNS?

Responses to WNS by many federal and state agencies have included closing caves on public lands to visitors, requiring or recommending decontamination protocols for selected people (such as bat researchers) who are allowed to visit caves, and public pronouncements that suggest, or even state, that the fungus associated with WNS is spread by people who visit caves. These actions target cavers and, at a minimum, stigmatize cavers and private cave owners as being environmentally insensitive and lacking an ethical concern for wildlife if they enter caves or permit others to do so. Such stigmatization would be justified only if it were supported by credible data, which is not the case. If agency actions lack credible support they are at least improper and unethical.

In states where WNS exists, and in nearby states, most caves are not on public lands where the agencies have authority to prohibit cave entry. While some agency personnel have recommended that private landowners close their caves to visitation because of WNS concerns, few owners have done so. Many landowners view such agency efforts as government intrusion upon private property rights and repeated agency press releases about expanding areas of infection enhances that perception. With the possible exception of federally listed species, agencies have little or no legal authority to require the closure of caves on private lands even if the caves contain bats. It appears that litigation related to this issue may occur in Wisconsin.

Some cavers in organized groups such as the National Speleological Society have complied with public agency cave closure policies by shifting their activities to caves on private property and adopting decontamination approaches. However, most cave visits are not by such groups and public awareness and compliance with the cave closure policies is generally minimal.

Conditions in Missouri illustrate the futility of the cave closure strategy. There are approximately 6,200 caves known in the state and about 75% of them are on private property. In terms of visitor numbers, I estimate that closure of all public caves in Missouri to visitation would reduce total wild cave visits in the state by about 5% since there is negligible enforcement of the closure orders and limited public compliance. Some cave visitors may be diverted from a cave on public land to one on private land, but this does not reduce total visitation.

Fighting a forest fire is an appropriate analogy for attempting to control the spread of WNS and *G. destructans*.

You cannot control a fire with a control line on only 5% of the fire perimeter, and (even if cave visitors were involved in spreading WNS) you cannot control the spread of WNS or the associated fungus with control on only 5% of the people who visit caves. Furthermore, using the fire line perimeter comparison, the 5% control is scattered along the fire line rather than concentrated in a particular area. There is no evidence that the closure of caves on public lands during the last six years has slowed (let alone prevented) the spread of WNS. The rapid spread of WNS clearly demonstrates both the failure and futility of the strategy. The strategy failed even when WNS was confined to a relatively small area in the northeastern U.S. There is no reason to expect the strategy to work any better when the perimeter of WNS infection has grown many times larger. The suggestion that the cave closure strategy may be of some benefit is specious and runs counter to the evidence; it is simply junk management based upon junk science.

Is WNS Spread by Cave Visitors?

G. destructans has been found on bats over an extensive portion of Europe, but does not appear to cause death in these bats (Wibbelt et al. 2010). Perhaps that is because European bats have some immunity to the fungus. Another possibility is that the underlying cause(s) of WNS is absent in Europe. Some agency press releases speculate that cavers transported the fungus to the United States on caving equipment that had been used in European caves. Simply because fungal spores can be detected on equipment that has been in a WNS infected cave does not demonstrate that cavers and caving equipment have actually transported the fungus from one cave to another.

Despite speculation, there is no evidence that people have transported the fungus and/or WNS from an infected cave to another cave where the fungus has become established or where WNS has been detected. Even if the fungus were transported to other caves by people, it must become established in the other caves and then somehow become established on bats. If WNS has been spread by people, the most likely culprits are bat researchers who have had direct contact through themselves or their equipment with both infected and non-infected bats.

Bat researchers working in caves and underground mines are now expected to use decontamination protocols, and this is undoubtedly better than in the earlier days of the WNS outbreak when there was often little in the way of decontamination efforts. Even with current decontamination protocols, it is unrealistic to expect such approaches used under field conditions to be highly, let alone totally, effective. Additionally, at least some bat researchers privately acknowledge that decontamination efforts will have little or no impact on the ultimate spread of WNS. As a result, and especially under adverse field conditions, the adequacy of their decontamination efforts is questionable. Finally, bat researchers trapping and handling bats outside of caves may also encounter both infected and non-infected bats, but at least some of these non-cave workers do not do any decontamination.

Studies have shown that WNS is spread from bat to bat and from an infected roost site to previously healthy bats. Many bat species use multiple roost sites over the course of a year and routinely have direct contact with other bats at multiple sites. Some bats move extensively over the course of their lives. As an example, Tuttle (pers. comm.) reports that banded grey bats from a cave in northern Alabama moved to Florida, Georgia, Kentucky, Tennessee, and across Missouri almost to Kansas.

Constantine (2003) made the following comments prior to the discovery of WNS. They are clearly relevant to the importance of bats in spreading WNS.

"Bats and the pathogenic organisms they sometimes harbor are being transported by humans within and between continents, and sometimes these transported bats escape. Because bats reproduce slowly (usually only one or two offspring are produce annually by a female), the chances of successful introduction of the species are minimized. Populations would more likely develop should large numbers be freed in places favorable to survival. Although a single escaped bat might not survive long or reproduce, it would seek shelter in places frequented by local bats to which it might transmit pathogens. As has been observed, introduced pathogens include RABV [Rabies virus], other lyssaviruses, or various other agents."

Bats are the primary (and perhaps exclusive) agent for spreading WNS. There is speculation, but no proof, that people who visit caves might be capable of spreading the disease. Barges, trains, aircraft, trucks, trailers, and shipping containers transporting WNS-infected bats to previously uninfected areas are likely to be important in spreading the disease to distant locations. However, efforts to reduce or prevent accidental transport of bats infected with WNS have a negligible chance of limiting the spread of WNS. When WNS appears at a new location it is almost certainly attributable to bat-to-bat contact resulting from the natural migration of bats or the occasional unintentional transport of WNS-infected bats. Any agency efforts to close caves to the public based upon the speculation that cave visitors may be capable of spreading WNS lacks scientific support and represents irresponsible agency management.

Are Caves the Only Bat Habitats that Warrant Management for WNS?

The focus of most agencies has been on the management of caves as the only bat habitats that warrant management for WNS. A few agencies have included abandoned underground mines in their closure regulations, yet the primary focus has been on caves. As far as I can determine, no agency management has given any attention to WNS management at other bat habitats including those in agency structures where there could be substantial contact between roost sites and people.

Caves provide a very small fraction of the total roost sites used by bats where bat-to-bat contact or roost-to-bat contact could spread WNS (Aley 2010). For example, Cleveland and Jackson (2007) found that 10% of the randomly sampled bridges in Georgia provided bat habitat. There are about 20,000 bridges and similar structures in Missouri (Aley 2010), so given the Georgia data about 2,000 of these would be expected to provide bat habitat, yet none of these are closed to public use due to WNS or *G. destructans* concerns. Bonewell et al. (2010) estimate that there are 23,000 abandoned mines (presumably underground mines) in Colorado. Moon (2010) reported that the Forest Service was considering closing 30,000 caves and abandoned mines in Colorado. Based upon these values, my estimate (Aley 2010) of 10,000 to 100,000 abandoned mines in the United States should be revised upward to more than 100,000. If we use the estimate in Aley (2010) that 40% of the mines provide bat habitat then this represents over 40,000 mines that provide such habitat. Finally, especially under warm-weather conditions, homes, barns, schools, churches, and other building provide an enormous number of bat habitat sites in close proximity to people. It is likely that many structures are at least as desirable for bat habitat as bridges.

During the summer, several of the bat species that have died in large numbers from WNS are commonly found in close association with people at roost locations that are neither caves nor underground mines. These locations include backyard bat houses, carports, garages, porches, attics, and other sheltered sites on homes and buildings. Cave visitors are only a minor fraction of the total human population that comes into relatively close contact with bats and bat roost and thus may have the potential to spread *G. destructans* or WNS.

Agencies clearly do not want to target homeowners with bats in their attics and carports, schools and churches with bats in the belfry and elsewhere, or at agency structures providing bat habitat. Do agencies that close their caves to the public under the guise of trying to limit the spread of WNS also prohibit entry to agency building that have provided bat habitat? Of course not; it would be silly and would harm the agencies. It is abundantly clear that efforts to limit the rate of spread of WNS by reducing human contact with bat habitats are not viable or realistic. There are tens of thousands of habitat sites in the U.S. and caves are only a tiny fraction of these. Finally, there are no data showing that bat habitat sites in caves represent a greater risk of spreading WNS via people than do sites in buildings and other locations.

Is it Reasonable to Manage Most or All Caves on Public Lands as Bat Habitats to The Exclusion of The Many Other Uses and Resources That These Features Provide?

We have probably all seen the U.S. Forest Service signs that state “National Forests: Lands of Many Uses”. Multiple use recognition must apply to caves on public lands (and not just Forest Service lands) since caves also have many uses. The multiple use concept is well established in public land management law and policy and applies to the subsurface as well as the surface. While it is appropriate to manage some caves on public lands primarily as bat habitats, it is inappropriate to manage all caves on public lands as bat habitats to the exclusion of their many other uses and resources. This is especially true since few caves provide substantial bat habitat. By prohibiting public access to all caves on National Forest lands east of the Great Plains the U.S. Forest Service may be in violation of the Multiple Use Act and perhaps other pieces of federal legislation. Other federal agencies may also have exceeded their legal authority by their blanket cave closures.

Most land management agencies have few employees with professional competence in the management of cave and karst resources. Such agencies commonly view caves as problem sources rather than as natural resource assets. Some agency bureaucrats may have perceived WNS as useful for limiting or excluding public access to caves, their “problem sites”. If so, that is clearly inappropriate public land management.

Likely Results of Continuing Agency Cave Closure Policies

Agencies are routinely reluctant to change management strategies except in the face of appreciable pressure. The easiest course of action for agencies will be to maintain cave closure policies and do so for a long time. Overt public resistance to such a course of action has been relatively minimal to date, although the strategy has created a reservoir of public ill-will toward the agencies and, to a somewhat lesser degree, toward bat researchers who have been instrumental in the adoption of the flawed strategies.

Bat scientists, at least so far, have been able to do the cave work they would like simply by getting permits from appropriate land management agencies and applying decontamination protocols. So far as I can determine, the effectiveness of such protocols as applied in the field has not received a scientifically credible assessment.

Courts give general deference to agency policies with the premise that such policies are factually based and generally reasonable. As a result, we should expect courts to presume that at least some of the transmission of WNS is due to cave visitors, that caves on public lands must be closed to minimize or prevent the spread of WNS, and that it is appropriate to manage most or all caves on public lands as bat habitats to the exclusion of other uses.

The National Environmental Policy Act (NEPA) requires the preparation of Environmental Impact Statements (EIS) for federal actions affecting the environment. As summarized by Gaskins (2000) an EIS must include a detailed statement on the following:

- The environmental impact of the proposed action.
- Any unavoidable adverse environmental effects.
- Alternatives to the proposed action.
- The relationship between short-term uses of man’s environment and the maintenance and enhancement of long-term productivity. [This is basically a cost/benefit analysis]
- Any irreversible and irretrievable commitment of resources if the action is implemented.

In view of the blanket cave closure actions by agencies such as the U.S. Forest Service and the presumption that people spread WNS, it is clear that any WNS research involving entry into bat colony areas in caves would require the preparation of an EIS by the agency with management responsibility for the particular cave(s). This would be especially true for studies that involved the handling and release of bats, particularly if multiple caves were involved in the studies. The role of decontamination protocols in minimizing adverse impacts is important and would obviously be evaluated in an EIS. It might be possible for an agency such as the USFWS to prepare an EIS on WNS research in caves that showed that decontamination protocols were totally effective and/or that the risk of human transport of WNS from one cave to another was negligible. However, in the absence of such an EIS and such a finding, it is clear that WNS research in caves administered by federal agencies must be suspended until the activities are addressed under the provisions of NEPA.

WNS research could go forward in caves on private or non-federal public lands as long as no federal funds were involved in supporting the research and there was no other federal nexus. As an example, a federal permit to pursue and capture federally listed species would constitute a federal nexus. Additionally, federal employees could not be involved in the research.

A National Science Foundation grant with five years of funding beginning August 1, 2011 has been awarded for a major WNS study. The grant has been awarded to a group including some of America's best bat researchers. However, implementation of this grant will result in a number of people going in many caves during the winter, summer, and fall and handling and swabbing the fur and exposed skin of bats. This will undoubtedly include bats that are both infected and not infected with WNS. Given the rationale that federal agencies have used to close caves to visitors, it is reasonable to conclude that the activities to be undertaken with the grant pose a substantial environmental risk of enhancing the spread of WNS. The principal investigator for the study has confirmed that no EIS has been prepared for this project. Unfortunately, preparing an EIS that is fully compliant with all the requirements of NEPA is no minor undertaking, nor can it be done quickly. As an illustration, an Environmental Assessment (which is an abbreviated EIS for projects with minimal risks of environmental impacts) was required for a group of hydrologic studies including one in which I am the principal investigator. The process required a year and necessitated public meetings, legal notices in newspapers, and public involvement to be fully compliant with NEPA.

It is not my wish to be the enemy; I am the messenger. If you seek villains they are the federal agencies that chose to make unworkable rules and make it appear (inaccurately) that they were doing a good job of protecting bats and the environment. What these agencies have actually done in their rule-making zeal is create a regulatory snare that will delay, or perhaps prevent, the very kinds of research that could benefit the bats.

Science-Based Management or Management Premised on Junk Science?

There is an old story that goes something like this. There was an emperor who purchased an incredible set of beautiful clothes that only intelligent people could see. The emperor could not see them himself, but wore them in public anyway. His subjects said nothing, but a child shouted: "The emperor has no clothes". In dealing with WNS the agencies have wrapped themselves in the junk science of unsupported assumptions, wishful thinking, and management strategies that have no reasonable chance of success. It is time for those of us with reasonable skills in science and natural resource management to tell the public that the fabric of the agencies' strategies has no integrity and that the responsible bureaucrats are standing naked in public. It looks a lot like the Woodpecker Escapade again.

As Offit (2011) discussed in the case of medical studies, junk science is not a victimless crime. In the case of cave closures in response to WNS the victims are the public that is being ill-served, the hundreds of agency personnel who do competent and ethical work, and those of us who use or own caves and are being stigmatized as environmentally insensitive by the continuing parade of agency publicity. The credibility of science also suffers when agencies suggest that their management is science-based when it is not. And finally, and most importantly, it is the bats and research that might benefit the bats that will suffer.

Most bat habitat in the United States is on private land, and bat-friendly ownership of that land is essential. Agencies' actions are highly counter-productive if they antagonize those who own and/or care about caves and cave habitats. Such agency actions must be stopped. Agencies can and should play important roles in the protection of bats, but the management approaches to date have caused harm without producing offsetting benefits. Agency management actions to date have focused on regulating people even though there is no credible scientific evidence showing that WNS is a problem caused or exacerbated by people who own or use caves. The problem is with the bats and the disease, not with the very people who will be critical in efforts to protect bats now and help those that escape or survive WNS in the future.

Efforts to limit the spread of WNS by focusing efforts on the fungus represent speculation-based, not science-based, management. Some may argue that focusing management actions on the fungus are appropriate since a pathogenic fungus lethal to bats would be the worst-case scenario. However, public policy based upon either worst-case or best-case scenarios is seldom good public policy. It was a fallacious worst-case scenario policy that forced Japanese-Americans into confinement camps after the Japanese attack on Pearl Harbor. The confinement was based on the specious presumption that those people might harm American interests during World War II. At the other end of the spectrum, it was a fallacious best-case scenario that directed the Ivory Billed Woodpecker episode.

Recommendations

Public policy related to WNS must be based upon reasonable and realistic scenarios, not scientifically unsupported speculations. As this paper demonstrates, that has not been the case to date. It is time to junk the junk science and the management strategies premised on it. Not only is this the right thing to do, it is also in the best interest of bats, caves, and the people who use and protect caves. Specious management strategies damage the credibility of agencies and scientists who have supported or tolerated such approaches.

I recommend that the U.S. Fish and Wildlife Service consider establishing a small professional panel of experts from <u>outside</u> of that agency to review existing management approaches for dealing with the WNS issue and to then recommend revised or new approaches. This approach would be timely, and is consistent with sound agency management. It might also provide some regulatory shelter for on-going research projects that have not complied with provisions of the National Environmental Policy Act. Additionally, such a panel (or a second panel) could be tasked with recommending improvements in the WNS research strategy. The current approach is for researchers to pursue topics of individual interest that 1) might attract funding, and 2) can be linked to WNS in some manner. While we would all hope that results from such studies could be melded into actions that might aid bats, such an approach is inherently inefficient and slow. Time is of the essence, and bats need and deserve a more focused problem-solving strategy than is provided by the current approach directed by the U.S. Fish and Wildlife Service.

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The U.S. National Park Service Response to White Nose Syndrome in Bats

Kevin T. Castle
Wildlife Health Branch
Biological Resource Management Division
National Park Service
Kevin_Castle@nps.gov
(970) 267-2162

Abstract

Thousands of caves and mines are administered by the U.S. National Park Service (NPS). Since 2008 the National Park Service has been preparing for the spread and effects of WNS through a proactive national program of response coordination, research support and interpretation, and education. Bats positive for WNS or Geomyces destructans have been detected at four sites in the National Park System, and have been detected within 100 miles of numerous units.

This presentation will provide information on how NPS units across the nation are uniquely situated to help educate the public, understand WNS and its ecosystem impacts, and assist in the conservation and recovery of affected bat species and cave ecosystems. This presentation will also provide insight into how the NPS manages its "dual mission" to provide both resource protection and visitor enjoyment, in the face of WNS, with specific examples of cave access management from several NPS units.

White-Nose Syndrome:
The State of Knowledge and Management in 2011

Jeremy T. H. Coleman
US Fish & Wildlife Service, Hadley, MA
Jeremy_Coleman@fws.gov

David S. Blehert
US Geological Survey, National Wildlife Health Center, Madison, WI

Eric R. Britzke
US Army, Engineer Research and Development Center, Vicksburg, MS

Paul M. Cryan
US Geological Survey, Fort Collins Science Center, Fort Collins, CO

Ann R. Froschauer
US Fish & Wildlife Service, Hadley, MA

Kevin Keel
Southeastern Cooperative Wildlife Disease Study, Athens, GA

Daniel L. Lindner
US Forest Service, Northern Research Station, Madison, WI

Joseph C. Okoniewski
New York State Department of Environmental Conservation
Wildlife Pathology Unit, Delmar, NY

Abstract

White-nose syndrome (WNS) has caused unprecedented mortality in hibernating bats in eastern North America. This previously unknown disease has spread rapidly since its discovery in New York in 2007, and poses a threat to hibernating bats throughout the continent. In 2010, DNA indicative of the fungus Geomyces destructans, the presumptive cause of WNS, was detected on bats as far west as Missouri and Oklahoma. The disease, WNS, and/or the fungus, G. destructans, has now been detected on bats at over 190 hibernacula in 19 states and 4 provinces. An assessment of wintering populations at 42 hibernacula across 5 northeastern states revealed a total loss of 88% of all bats in sites that have been affected for more than 2 years, with colony losses at some sites exceeding 99%. While our understanding of this disease has improved considerably, there are many questions that remain to be answered. The nature of remnant bat populations in the affected area has not yet been determined, and the potential for resistance within affected species has not been demonstrated. We also do not know the actual distribution of G. destructans on the landscape and lack the tools to manage the fungus once it becomes established. A coordinated effort is required to manage WNS and conserve North American bats, and there are over 100 state and federal agencies, tribes, universities, institutions, organizations, and private entities involved with the organized response. The National Plan for Assisting States, Federal Agencies and Tribes in Managing White-Nose Syndrome in Bats, finalized in May 2011, provides the framework for a coordinated national response.

Implementing a White-nose Syndrome Response Plan at Lava Beds National Monument

Shane Fryer[1], Shawn Thomas[2], and Katrina Smith[3]
Lava Beds National Monument
P.O. Box 1240
Tulelake, CA

[1]Shane Fryer
shane_fryer@nps.gov, 530-667-8150
[2]Shawn Thomas
shawn_thomas@nps.gov, 530-667-8150
[3]Katrina Smith
katrina_smith@nps.gov, 530-667-8150

Abstract

White-nose syndrome (WNS) could impact vulnerable bat resources at Lava Beds National Monument. In response to this threat and to comply with the National Park Service Deputy Director's 2009/2010 memos, Lava Beds National Monument has adopted a WNS Response Plan. Multiple strategies were introduced in order to overcome geographic and operational challenges. Goals of the plan include mitigating the human-assisted spread of WNS, furthering bat protection efforts, allowing for cave visitation, and increasing public awareness of bats and WNS. Initial observations identified a small, but high-risk group of visitors that interact with caves. Through the strategies of Education and Outreach, Targeted Cave Closures, Visitor Screening, and Adaptive Management, the stated goals of the Response Plan were met. During the 2011 summer season, implementation of the plan resulted in screening of over 25,000 visitors and decontamination of gear from over 130 visitors. These initial efforts have garnered public cooperation and positive visitor feedback.

Introduction

White-nose syndrome (WNS) has the potential to severely impact vulnerable bat resources at Lava Beds National Monument. Bats are a critical ecological component of the monument's cave and surface environments. In response to the threat of WNS and to comply with the National Park Service Deputy Director's 2009/2010 memos, the monument's resource management staff developed a WNS Response Plan.

The initial draft of the WNS Response Plan was completed in December 2010 and was reviewed by other National Park Service (NPS) cave specialists, NPS biologists, and outside bat researchers. In January 2011, the Draft WNS Response Plan was presented to the Lava Beds management team, and an interdivisional WNS Working Group was convened to begin drafting an implementation plan and budget for the program.

Four goals were adopted to guide the monument's response: 1) Reduce the chances of human-assisted spread of white-nose syndrome to local bat populations; 2) Allow populations of bats to benefit from undisturbed reproduction and hibernation in preparation for the anticipated arrival of white-nose syndrome; 3) Allow for continued visitor use in selected caves where screening mitigates the risk of human-assisted spread of white-nose syndrome; and 4) Increase public awareness of white-nose syndrome and its potential impacts.

The WNS Working Group in turn refined four strategies to help meet these goals:

- Education and Outreach
- Targeted Cave Closures
- Visitor Screening
- Adaptive Management

By March 2011, the final WNS Response Plan was completed and limited implementation began. Full implementation of the plan was in place by May 2011.

Background

Lava Beds National Monument is a substantial cave park in the NPS system, managing a scale of accessible resources on par with other major cave parks like Wind Cave, Mammoth Cave, and Carlsbad Caverns. Lava Beds was established in 1925 to preserve the unique geologic, natural, and historical features of the landscape. Sixty-one percent of the 46,560 acres within the monument are covered by basaltic lava flows. The monument protects a wealth of cave resources, including the highest concentration of lava caves within the contiguous United States. Currently, over 750 caves have been documented within the monument. Twenty-one of these caves have undergone development, including trails, steps, and other infrastructure that facilitates visitor use. These infrastructural developments allow access to approximately 8.5 miles of cave passage.

Lava Beds is one of the most significant bat sites in the state of California. The monument's volcanic landscape contains caves and countless rock crevices for roosting and hibernating bats. The presence of forest habitat provides refuge for tree-dwelling bat species. In total, 14 bat species have been confirmed within the monument. The prominence of bats as an important monument resource led to the establishment of long-term bat monitoring and protection programs. Starting in 1988, summer interns began to assess the locations and sizes of bat colonies, while establishing a database for bat observations. Cave closures related to bat presence began in 1993. Four years later, the bat management program was expanded to include long-term monitoring of hibernacula and summer outflights. Cave closures were expanded to protect newly identified roosts, and surveillance equipment was installed to detect unauthorized human access.

Past monitoring efforts have largely focused on three bat species. The monument provides critical habitat for the largest known populations of the Townsend's big-eared bat (*Corynorhinus townsendii*) and the Brazilian free-tailed bat (*Tadarida brasiliensis*) in the state. Significant populations of the pallid bat (*Antrozous pallidus*) also reside in the monument. Currently *C. townsendii* and *A. pallidus* are the only species of bats occurring at Lava Beds that have been recognized as Species of Special Concern (SSC) by the California Department of Fish and Game. Presently, three *C. townsendii* maternity colonies are known to exist in the monument, with the largest hibernaculum site hosting on average over 550 bats every winter and a total of over 1100 bats at all known hibernacula sites combined. Two *A. pallidus* colonies have been identified, and summer surveys have tallied the largest colony at over 100 individuals. Most of the knowledge about the monument's population of *T. brasiliensis* is a result of studies and protocols developed by Steve Cross of Southern Oregon University. He established a site-specific photographic protocol that estimates population size (pre- and post-volancy of pups) from the outflight of this species. Since 1988, monument staff have continued annual photographic monitoring of outfight emergences during the summer maternal season (June - September). This monitoring has revealed a *T. brasiliensis* colony size that ranges from approximately 60,000 to 250,000 individuals.

Less is known about the other 11 bat species that reside at Lava Beds, including, among others, a number of *Myotis* species that may be susceptible to WNS. Initial studies on other bat species include acoustic monitoring transects conducted by Bat Conservation International (BCI) in 2010 and ongoing acoustic monitoring conducted by monument staff, using bat detectors and digital recorders to collect bat calls. Reviews of acoustic surveys demonstrate a high level of bat activity throughout the monument, with a sizeable number of calls from *Myotis* species, including calls from the little brown bat (*Myotis lucifugus*). Previous mist netting surveys are consistent with these findings and identify significant activity of several *Myotis* species. Currently, *Myotis* bats show no fidelity to known maternity or hibernacula cave sites within the monument, suggesting that they are instead occupying rock crevices or possibly unknown cave sites.

Problem Statement

The difficulty of managing cave resources at Lava Beds is largely due to the geographic distribution of caves, the history of infrastructure development, and previously accepted visitation practices.

Nearly all of the monument's caves that visitors regularly access are contained within the Mammoth, Valentine, and Caldwell basalts. These geologic formations have been the focus of most past development, and at present accommodate the majority of the monument's trails and roads. This infrastructure, in addition to allowing access to developed caves, also enables informal access to many undeveloped caves, despite those caves being largely managed for their intrinsic and habitat values.

Issues of access have been even further compounded by the circumstance that most visitor services are provided at the Visitor Center, which was centrally placed, making it distant from the monument's four points of entry. This creates a challenge in trying to contact all visitors before they enter caves, as visitors must pass by cave trailheads and access points on their way to the Visitor Center. One exception is a seasonally open fee station on the north end of the monument, which has been invaluable in improving visitor awareness of WNS and ensuring compliance with WNS management.

By far, the greatest challenge has been revising decades of previously accepted visitation practices at Lava Beds and, more generally, in volcanic cave parks of the NPS. The NPS as a whole demonstrates a protective bias toward solutional cave systems developed in limestone or marble; access to these caves is typically controlled through mandatory guided tours and/or permits. In contrast, the lava caves of volcanic cave parks of the NPS have a history of self-guided visitation. This management divide may be unintentional; however, the effects are tangible, as lava caves remain susceptible to a higher incidence of cave resource impacts relative to solutional caves. To be clear, neither the Federal Cave Protection Act of 1988 nor the NPS Management Policies 2006 express favoritism for cave origins or call for differing management strategies based on cave origin. Rather, this divergent management has occurred due to differing levels of compliance with NPS policy, resulting in two very distinct cave visitation paradigms: One is a guided, scholastic visitor experience typically found in developed limestone/marble caves, and the second is an unguided approach with the emphasis on individual exploration and recreation indicative of volcanic cave parks.

The formal guided tour setting of solutional cave parks allows for "one on one" messaging during ticket sales, group safety orientations, and throughout interpretive programs. The establishment of a WNS screening station within the park creates another level of contact and protection. The limestone/marble cave visitation model inherently has multiple levels of interaction, visitor education, and resource protection. In response to WNS, the volcanic cave visitation model has been a challenge to revise in a way that provides required interaction with visitors, as in the past visitor contact with staff has primarily occurred on a voluntary, less formal basis. Cave visitation at volcanic cave parks largely remains a self-guided experience, and adapting this visitation model to provide multiple levels of visitor management and contact, including WNS screening, has been difficult.

Methods

To surmount the geographic and operational challenges mentioned above, Lava Beds has implemented four strategies: 1) Education and Outreach, 2) Visitor Screening, 3) Targeted Closures, and 4) Adaptive Management.

Education and Outreach

The public's general unawareness of WNS and related operational changes (visitor screening and decontamination) at Lava Beds was regarded as the initial obstacle by the WNS Working Group. In response, the Education and Outreach component of the program was prioritized early on. The interpretation and resource management divisions worked closely to train and educate staff on WNS and Lava Beds' response plan and to develop clear and accurate messaging to present to the public.

Prior to the WNS program being initiated, a wide reaching media campaign was implemented. The monument directed press releases to multiple media sources, while encouraging local newspapers to develop more in-depth articles. Interviews were also given to local public radio outlets. The media campaign was followed by educational material and notifications of operational changes sent to schools, tour bus operators, and recreational groups. WNS bulletins were created and displayed at local restaurants, climbing gyms, hotels, and public buildings, and staff actively restocked educational materials in the local community as necessary.

Finally, WNS media was developed specifically for Lava Beds and our visitors. The monument's website was updated to include WNS information and links to other WNS resources. Within the monument, posters, pamphlets, and interpretive programs were developed or modified to provide multiple avenues of education to the public.

Targeted Cave Closures

The WNS Response Plan called for the year-round closure of 12 backcountry sites that were determined to be significant hibernacula based on a threshold number of bats recorded during winter surveys and based on fidelity of hibernating bats to the site. Additionally, three frontcountry, visitor-use sites received temporary closures during the winter hibernation season. These closures were consistent with guidance provided in the "National Park Service WNS Caving Decision Tree." Decades of active bat monitoring has enabled the monument to make well informed assessments of cave status, allowing the monument to target and prioritize caves where bats would be most susceptible to disturbance and the potential introduction of WNS. Backcountry hibernacula remain closed year-round, with the exception of administrative access for monitoring and/or research, provided that proper preventative measures have been followed to avoid potential contamination. Visitation at seasonally closed frontcountry sites was only allowed after the hibernation season had ended and once screening operations were deemed effective. Seasonal closures of summer maternity caves remained consistent with previous years.

A critical element to Targeted Cave Closures is informing the public as to why these restrictions are necessary. Prioritizing the WNS response program with an Education and Outreach push was critical to gaining the acceptance of new WNS closures from the public. Lava Beds also has a nearly 20-year history of managing seasonal cave closures to protect both hibernacula and maternity use sites, so the Targeted Cave Closures strategy was merely an expansion of the existing closure program. The monument has been highly successful at using surveillance equipment and signage to deter intrusions into closed sites, and these methods were applied to new WNS closures.

Visitor Screening

The WNS screening process at Lava Beds was designed to be quick, informative, and as least intrusive as possible while also being effective, which requires honest responses and adherence to monument rules. The monument's interpretive staff conducts the screening and have strived to make screening a positive and educational experience. Screening also provides the opportunity for visitors to connect with the resource and apply what they have learned to future monument visits and to other cave areas.

In order for visitors to access any cave resource, Visitor Screening is required. A visual screening tool was adapted from the one in use at Mammoth Cave National Park for their WNS response program. This simple flow chart graphically illustrates the screening questions and prerequisites for cave visitors' gear. The monument's screening process follows this chart, which determines if any article of clothing or equipment has had the chance of coming into contact with *Geomyces destructans*, the fungus responsible for the WNS disease in bats. During the screening process, if a piece of gear is determined to pose a potential threat of contamination, visitors are initially asked to leave that item in their vehicle and not bring it into the monument's caves. While visitors often have a spare jacket, many times alternate footwear isn't available. In cases where a visitor has no substitute, the monument offers decontamination of exposed gear. Decontamination procedures follow U.S. Fish and Wildlife Service standards, including thorough brushing to remove sediment and a 10-minute submersion in Lysol® IC Quaternary Disinfectant Cleaner for footwear. Non-submersible items such as cameras are thoroughly cleaned with Lysol® Disinfecting Wipes.

To ensure all visitors are screened, signs at the monument's four entrances and at all cave access points inform visitors that screening and a WNS Pass are required for cave entry. After screening is complete, a WNS Screening Pass is issued and placed on the vehicle windshield of screened groups and individuals. Roving interpreters, as well as protection rangers and resource management staff, can easily search parking areas to verify that all vehicles have a Pass displayed. If vehicles are found without a Pass, these visitors can be identified and screened on site.

Adaptive Management

At this time there are still many unknowns about WNS. Our understanding of WNS as an infectious disease is still evolving, as are the best management strategies to reduce the risk of this threat. As new research is published, or as better management practices are proposed, Lava Beds endeavors to institute Adaptive Management in order to best protect bat resources. The monument continually observes WNS research, policy, and management developments that could initiate changes in future operations.

The internal policies of the Department of the Interior and the National Park Service have strongly influenced the WNS response at Lava Beds and will continue to serve as guidance for future direction of the program. Additionally, the management prescriptions of sister agencies, findings from State Steering Committees and National Working Groups, and comments from specialists and cooperating citizens will continue to be influential in informing the best management practices in responding to WNS.

Research on WNS and new knowledge on the ecology and transmission of the disease is paramount to planning response efforts and understanding how effective those efforts may be. Research or observations that confirm the infection of the Townsend's big-eared bat or the pallid bat, both listed as Species of Special Concern in California, would raise many management concerns, as the monument has a long history of managing specifically for these bat species. Developments in the progression and spread of WNS may also call for changes in future management. For instance, a geographic jump of WNS across the Rocky Mountains and into the Great Basin and the western U.S. may provoke a more progressive media campaign and/or the implementation of more controlled visitation practices, such as guided tours. Additional research on WNS and *G. destructans* may reveal the efficacy of current practices or suggest new management tools. Fungal spores of *G. destructans* have been identified on contaminated gear, in cave sediments, and at hibernation sites, however, the parameters of its residence time and viability are still unknown; this information would help to refine decontamination protocols. Decontamination of cave gear typically relies on quaternary ammonium compounds, and future research may determine detrimental effects of disinfectant cleaner residues on the cave environment; of chief concern are the health of cave obligate invertebrates and microbial life. This knowledge would also contribute to refining decontamination protocols and achieving a balance between reducing the threat of introducing WNS while also maintaining healthy cave ecosystems.

Results

Screening of visitors started in late March 2011, with full implementation of the WNS response program up and running by the beginning of May, when a dedicated staff was hired to provide visitor screening, decontamination, and education. WNS screening will continue until a future management decision modifies or terminates the program.

Based on data collected between the end of May and the beginning of October 2011, a total of 25,594 visitors were screened during this time period. July received the highest visitation of any month with 9,031 individuals screened. A total of 131 decontaminations were conducted on boots, helmets, and cameras during the May-October time period. The majority of decontaminations (83) came from buffer states that are currently WNS free but for which the monument still conducts decontamination as a precaution. Incidentally, 28% of our decontaminations resulted from prior visits to Wind Cave and Jewel Cave, NPS sites in South Dakota with whom we share the most visitor overlap. Of the 131 decontaminations, 48 were the result of visitation that came from a state that has confirmed the presence of WNS; these decontaminations define what the monument considers the elevated risk group. Of the 48 visitors in the elevated risk group, half had visited Mammoth Cave National Park in Kentucky. Mammoth Cave currently has a rigorous WNS program that includes pre- and post-decontamination procedures and has yet to observe WNS in their bat populations during routine monitoring. Lava Beds identifies the remaining 24 visitors as the high-risk group, with the greatest probability of carrying WNS. On average, the interpretation division decontaminated one visitor per day, with a total of seven decontaminations being the highest performed in a single day. One in 200 visitors required decontamination, and one in 1000 visitors were identified as being at high risk of transferring WNS.

During this same time period, interpretation and resource management staff conducted 22 checks of cave access points to determine compliance with screening. Observations were conducted on weekends and over the holidays when visitation was high. A total of 401 vehicles were checked, and over 95% of these vehicles contained a properly displayed WNS Pass. Only 18 vehicles were identified as being possibly non-compliant based on lack of a WNS Pass. Visitors associated with some of these vehicles were screened on site and none required decontamination. A number of other vehicles displayed monument receipts but not a WNS Pass, making it likely they had incorrectly carried the Pass with them into the cave, rather than displaying it on their windshield. Notices to receive screening at the Visitor Center were left on all vehicles that did not have a WNS Pass displayed. Protection rangers regularly monitored parking areas for unscreened groups and provided on-site screening when necessary. When consulted, protection staff stated that they have observed a high level of compliance and that the need to intervene was not a regular occurrence.

The last line of protection for the monument and the protection staff included an addition to the Superintendent's Compendium under 36 CFR 1.5 (Code of Federal Regulations):

> "No caving gear, clothing, footwear, cameras, etc. will be allowed in any cave if those items may have been contaminated with white-nose syndrome fungal spores as determined by a cave screening process. If the items can be properly decontaminated in accordance with the white-nose syndrome decontamination procedures, then those items would be permissible. This determination is based on the need to protect bats from being introduced to white-nose syndrome."

This allowed the protection staff to enforce the regulations relating to the screening process, including citing an individual for violating a cave closure if needed. The protection staff as well as all monument staff preferred education over penalty, thus no citations were issued during this time period.

Staff implementing the WNS response program at the monument have been heartened to find that the visiting public has shown a great deal of support for the program. Largely due to the work of Bat Conservation International, the National Speleological Society, and bat educators, misconstrued fears and myths surrounding bats are fading. There still is a lack of awareness about WNS, however, the monument's visitors generally recognize the importance of bats and express concern for their well-being.

Conclusion

The monument has endeavored to develop an adaptive WNS Response Plan. A small, but high-risk group of visitors that interact with cave resources at Lava Beds has been identified. Maintaining the continued capacity to recognize and decontaminate high-risk visitors will be needed into the foreseeable future. This capability requires staff and logistics, which are currently being funded through collected fees. In the long term, continued draws from these funds will have a detrimental effect on other areas of park operations. Future alternate funding sources to sustain WNS programs are needed and will be essential to maintaining the Lava Beds WNS response program.

This program is a reaction to the threat of WNS. Many cave environments display high levels of endemism and obligate life. Other insulated environments show vulnerability to invasive species and diseases; caves are no exception. Once introduced, alien species are nearly impossible to extricate. In the long term, cave parks will benefit from developing preventative measures that extend protection to vulnerable cave ecosystems and cave obligates species. The adoption of the WNS response program has allowed the monument the opportunity to experiment with a new method of managing visitation, which has led to increased interaction with visitors and positive feedback. Hopefully, preventative techniques and methods learned will be applied to future cave management plans.

The monument believes that the initial implementation of the WNS response program has met the Plan's original stated goals. Screening for WNS has been instituted, along with a previously unprecedented level of staff and visitor interaction and education. As public awareness of WNS and adherence to precautions continue to grow, the screening process will likely become more streamlined and effective. Early cooperation and positive visitor feedback optimistically points to the long-term success of the program.

Bat Surveys, Bat Gates & Radiation-
Bats in Utah Abandoned Mines 1995-2010

Anthony A. Gallegos
Senior Reclamation Engineer
Utah Abandoned Mine Reclamation Program
1594 West North Temple
Salt Lake City, Utah 84114
801.538.5267
anthonygallegos@utah.gov

Abstract

The Abandoned Mine Reclamation Program (AMRP) in Utah began in 1983. The program was closing abandoned mine openings without surveying for bats until 1995. From 1995 to the present day the AMRP has performed underground mine surveys for bats as a standard part of project development. Over this fifteen-year span the AMRP has collected bat survey data from over 40 projects addressing approximately 3,000 abandoned mine openings. Since 1995 the AMRP has installed bat compatible closures or excluded bats prior to closure as a standard part of closure construction. The AMRP has installed bat gates in abandoned uranium mines in the past, but this practice may be eliminated due to the concern with radiation exposure for bats.

This paper provides: (1) a statewide summary of the AMRP bat surveys (number of surveys, estimated cost, number of mine openings surveyed, mines with bats present or signs of bat use), (2) an overview of the bat compatible and non-bat compatible closure designs, estimated number statewide and costs, and (3) an overview of radiation exposure for bats in abandoned uranium mines.

Responding to the Threat of White-Nose Syndrome at Oregon Caves

Elizabeth Hale, GIS Specialist
Oregon Caves National Monument, National Park Service
Elizabeth_Hale@nps.gov

Poster only

Oregon Caves National Monument began screening visitors in 2011 to prevent the human-aided spread of the fungus associated with white-nose syndrome in bats. In the first three months of the 2011 tour season, the screening process effectively intercepted more than twenty instances of visitors wearing or carrying an item that had been used in a cave or mine within 500 miles of an affected site or in Europe, resulting in actions to exchange clothing or disinfect footwear or glasses. Additional measures were implemented to avoid white-nose syndrome, including screening employees when they enter on duty, modifying cave tour routes in spring and fall to avoid hibernating bats, permitting only dedicated caving gear in Oregon Caves, outfitting off-trail caving groups with coveralls, increasing bat surveillance, and developing outreach to build awareness of the disease.

The Utah Bat Conservation Cooperative
A Statewide Framework for Bat Management

Kimberly Hersey and UBCC members

Abstract

The Utah Bat Conservation Cooperative (UBCC) is an organization with the goal of conserving bat populations, communities, and habitats in the state of Utah through the joint efforts of various federal, state, university and private agencies with a stake in bat management. The partnership emphasizes science-based proactive management and provides input to natural resource planning, project development, and implementation efforts addressing bat related issues. Other objectives of the UBCC are to promote bat education to the public, provide training opportunities for UBCC members, and develop and prioritize bat research needs. Successes include consolidating all known historic Utah bat data into a web-based database, developing and implementing a standardized survey protocol, and providing bat capture and handling training. Current challenges include identifying important cave and mine habitats and developing prevention and response plans for the threat of white-nose syndrome.

Building a Diversified Monitoring Program for Cave-Dwelling Bat Populations

Shawn Thomas
Lava Beds National Monument
P.O. Box 1240, Tulelake, CA
Correspondence: shawn_thomas@nps.gov,
530-667-8150

Abstract

Bat monitoring has long been an important component of cave management, and the use of monitoring efforts to understand bat activity and cave use by bats has in many cases informed bat protection efforts such as seasonal cave closures, as well as bat education and conservation measures. A number of bat monitoring methods have been used through the years, some quite successfully, while more recently new technology has begun expanding the range of potential in bat monitoring. Long-term bat monitoring programs are often based on traditional methods such as in-cave surveys and outflight counts, which can be effective for monitoring bat roosts and populations when conducted consistently. Acoustic bat monitoring encompasses a broad range of equipment and methods, from recording bat calls and attempting taxonomic identification to logging the activity levels of bat colonies based on the magnitude of bat calls. Acoustic monitoring shows promise as a reliable means of collecting landscape-scale data on bat activity and occurrence, information which has become even more relevant with the current threat of white-nose syndrome (WNS). Building a successful bat monitoring program can be achieved by developing monitoring protocols that ensure long-term implementation, while also integrating data management procedures with program goals. This paper examines some of the current leading bat monitoring methods, based on experience at Lava Beds National Monument, and makes recommendations for implementing long-term bat monitoring programs.

Purpose and Need

Bat species that use caves comprise a critical component of cave, as well as terrestrial, ecosystems. As such, bat monitoring programs are critical to understanding the status and trends of cave-dwelling bat populations. In caves where bats roost, they play an important role in providing nutrients to cave ecosystems that are generally nutrient poor. In some caves, bat guano deposited at roost sites and along flyways may constitute the primary nutrient source for the system, providing the foundation for cave biological communities, including microbes, fungi, and invertebrates. In other caves, bat guano may be a minor, but still important, component of an already nutrient rich system. Cave-dwelling bats use caves for a significant part of their life cycle, but for feeding, bats must forage above ground. As part of the terrestrial ecosystem in the United States, bats are generally nocturnal and follow either insectivorous (insect-feeding) or nectarivorous (nectar-feeding) diets. Insectivorous bats are the most common types in the U.S., and their feeding behavior contributes to controlling certain insect populations and reducing agricultural pests [Boyles et al. 2011]. Nectarivorous bats are important in the southwestern U.S. for their role as pollinators of many desert plants, especially in the Sonoran Desert, where bat species from the family Phyllostomidae feed on nectar and pollen from cactuses and agaves [Horner et al. 1998; Fleming et al. 2001]. Given the importance of bats to both surface and subsurface ecosystems, and because many bat species rely on cave habitat for their survival, monitoring of bats and bat roosts is necessary for understanding the health of bat populations and protecting critical bat habitat. Bat monitoring can reveal the status and behavior of populations and contribute to bat protection efforts by identifying important bat sites and determining their time of use in bat life cycles.

More recently, the rise of white-nose syndrome (WNS) [Blehert et al. 2009; Cryan et al. 2010] has placed greater emphasis on the need for long-term bat monitoring methods capable of documenting baseline status of bat populations pre-WNS and understanding the possible impact of WNS on those populations. This is of particular importance in the western U.S. where bat populations have generally been more difficult to detect and are therefore less understood relative to bats in the eastern U.S. For example, the little brown bat (Myotis lucifugus) is one of the most common North American bat species and forms large colonial aggregations in eastern caves [Frick et al. 2010], whereas this same species is present in the west but is rarely documented in large aggregations. Conversely, western populations of the Townsend's big-eared bat (Corynorhinus townsendii) are relatively easily detected and thus have received more attention from research and monitoring efforts; still, understanding the population status of this species would benefit from expanding current efforts across the species range. Implementing bat monitoring programs in the western U.S. will help cave managers understand the current status of bat resources and provide a reference for measuring the potential effects of WNS on western bats. Furthermore, monitoring and surveillance will increase the chances of early detection of WNS [Duchamp et al. 2010], which will provide the greatest chance for conservation measures to be accomplished by integrating scientific knowledge and resource management strategies.

Bat Monitoring Methods

Numerous bat monitoring methods exist, many of which are beyond the scope of this paper. A broad overview of monitoring techniques and problems, along with recommendations, was produced through a workshop held by the U.S. Geological Survey in 1999, and the associated report [O'Shea & Bogan 2003] provides an in-depth analysis of bat monitoring methods. This report is an excellent reference that contains information relevant to Microchiropteran bat species of the continental U.S. and even Megachiropteran fauna from Pacific territories of the U.S. The report also treats a diversity of bat habitat types, including caves, crevices, mines, forests, and buildings.

Conversely, this paper presents recommendations based on monitoring efforts at Lava Beds National Monument and focuses on three categories of bat monitoring:

- in-cave surveys
- outflight counts
- acoustic monitoring

In-Cave Surveys

In-cave surveys of roosting or hibernating bats may be the oldest and most widely used method of monitoring bat populations in the U.S. Visibly searching caves for bats is a relatively straightforward monitoring method; however, care needs to be taken in establishing protocols for efficiently and effectively surveying caves while also ensuring that bats are not disturbed. Conducting a confident inventory of bat use at a site will usually require multiple site visits occurring across the seasons. Cave managers should always document bat monitoring efforts by cave/site, which allows analysis of bat population trends at cave-specific and/or area-wide levels. For the purposes of this paper, in-cave surveys will be broken into: 1) winter (hibernacula) surveys and 2) summer (maternity) surveys.

Winter (hibernacula) Surveys

Despite the necessary input of time and trained personnel, winter surveys are generally the most practical and effective method for determining population levels and trends. This is largely on account of the high fidelity of cave-dwelling bats, which tend to hibernate in the same sites from year to year. Provided that significant hibernacula have been identified in a given region, this method allows population censuses to be conducted with relatively low disturbance to bats. For winter surveys to contribute to a successful monitoring program, though, requires that counts are conducted consistently and methodically at all designated sites.

Because winter surveys are among the best methods for long-term monitoring of bat populations, it is extremely critical that survey sites are carefully chosen and consistently monitored. In an area where a hibernacula monitoring program does not yet exist, it will be necessary to conduct inventories of potential hibernacula during the winter to determine which caves contain hibernating bats and the magnitude of bats in each site. Based on inventories, sites can be chosen that represent the most significant hibernacula for an area, and these sites will need to be monitored on a consistent basis. Even for existing hibernacula monitoring programs, it may be necessary to review past data to evaluate if the program is achieving the goal of the monitoring; that is, can the data being collected be used to track long-term population trends? To meet this goal, it is important that all sites are counted during each survey season to provide for consistent, comparable datasets representing each monitoring season.

The timing of surveys is also an important component of an effective hibernacula monitoring program. Some bat species naturally arouse during hibernation, and movement of hibernating bats both within and between sites is known to occur during the winter [Thomas 2011a]. All sites should be surveyed in as short a window of time as possible to minimize the possibility that bats will be double counted or missed if movement occurs between sites.

Finally, weather may be a factor influencing the success of hibernacula surveys. There is currently no consensus among bat researchers as to the ideal weather conditions for conducting winter surveys. If surveys are conducted during times of cold, stable weather, this may decrease the chance of disturbing bats, as they are likely to be in deep torpor; however, if bats are disturbed while in deep torpor, their arousal from this state will be accompanied by a high energy cost. Alternatively, surveying during a period of relatively warm winter weather may increase the likelihood of disturbing and arousing bats. It may be best to find a compromise and conduct surveys during times of "average" winter weather for the area.

As always, surveyors should consider their potential impact to hibernating bats and conduct surveys as cautiously as possible with the goal of minimizing the amount of time spent in each site. It is best to use trained surveyors who are competent at spotting and identifying bats and also able to move through the cave environment in a quiet and efficient manner.

Summer (maternity) Surveys

Summer season surveys are generally aimed at detecting the location and activity of bats during the maternity season, which includes the time period when bats are breeding, giving birth to their pups, and raising pups to volancy (when pups are able to fly). After the maternity season, groups of bats begin to disperse in anticipation of fall swarming and hibernation. In-cave surveys during the summer may be successful at finding bat colonies, as well as additional solitary bats. Identifying the location of large aggregations of bats during the maternity season is an important step in developing an effective seasonal cave closure program designed to protect sensitive species of bats. Such programs have been effective at protecting maternal groups of Townsend's big-eared bats (Corynorhinus townsendii) at Lava Beds and other NPS sites.

Summer surveys do need to be conducted with great care, however, as C. townsendii and other bat species can be highly susceptible to human disturbance. In-cave surveys during the non-hibernation season should focus on counting individuals or very small clusters of bats (e.g., < 20 bats), whereas larger colonies, when encountered, should generally not be counted inside the cave due to the threat of disturbance, which may cause dispersal of the colony and potential abandonment of pups. In some cases, it may be possible to obtain in-cave counts of larger colonies if it is possible to use binoculars and maintain a substantial distance that will minimize disturbance; even in this situation, however, surveyors should conduct counts quickly and exit the area as soon as possible, as noise and lights may still cause disturbance from a distance. Colonies should be recorded when located, and surveyors should quickly leave the cave or cave area to prevent any additional disturbance. In many cases, it is possible to document the presence of a colony by sound, as maternal aggregations are usually quite chatty, and the pups in particular often emit loud, high-pitched vocalizations. Surveyors may also be clued in that they are approaching a colony if they observe one or more bats that have flown from down passage in the cave; these "scout" bats will often fly circles around the surveyors, then retreat further into the cave. This may occur several times before reaching the location of the colony, and surveyors should be cautious and prepared to turn around and exit the cave when encountering this type of bat behavior.

Conducting population counts during in-cave summer surveys is usually not feasible without causing significant disturbance to colonies. For this reason, documenting the date and location of maternity groups of bats is far more important in characterizing the summer bat activity of an area. This data will be the most important in determining significant bat roosts and developing a bat protection program. In comparison, the actual number of bats in a maternal colony is not as relevant as documenting their cave roosts and dates of occupancy; however, for establishing general population sizes of colonies, two common methods exist. First, if a colony is visibly located in a site, the population can be estimated based on the surface area occupied by the bats and their packing density. This method generally yields poor accuracy and is dependent on how well the bats can be seen and how familiar surveyors are with inferring counts from colony sizes. Also, attempts to view a colony for the purposes of estimating their size could easily be offset by the disturbance resulting from surveyors approaching bat colonies with bright lights. Given its unreliability and potential for disturbance, this method is not recommended. An alternative is to conduct an outflight count. If a colony is located in a cave that is suitable for conducting an outflight count (e.g., small number of cave entrances), then surveyors can return in the evening to count the bats as they emerge from their roost.

Outflight Counts

Outflight counts, also known as evening emergence counts [Kunz 2003], are used to count bats as they emerge from cave roosts. These counts range from simple direct counts of small colonies to relatively complex photo-estimation methods used for large colonies. For conducting censuses of maternity colonies using cave roosts, outflight counts may provide the best method for establishing population estimates, and they represent a low-disturbance alternative to in-cave counts. Outflight counts should not be considered absolute counts, though, as their accuracy can be affected by a number of factors. Significant factors that should be considered when conducting outflight counts include: 1) number of cave entrances, 2) bat behavior, 3) ambient light conditions, and 4) colony size.

Number of Cave Entrances

Outflight counts are generally only reliable when the roost is a cave with a small number of entrances. Because all entrances need to be surveyed to ensure that all bats entering and exiting the cave are observed, as the number of entrances in a cave increases, the complexity of the outflight count also increases. Also with more entrances, the integrity of the count decreases due to compounding inherent survey error from each entrance. Therefore, the fewer the cave entrances, the more reliable the outflight count. At Lava Beds, outflight counts are rarely conducted on caves with more than three entrances due to the reasons described above.

Bat Behavior

Bat behavior is another significant factor that can affect the accuracy of an outflight count. At Lava Beds, most outflight counts are conducted on colonies of Townsend's big-eared bats, and the emergence behavior of this species can make counts challenging. At the start of an outflight, these bats typically swoop in and out of the entrance repeatedly before ultimately exiting the cave. During the emergence, bats will often leave the cave entrance area to fly into the associated cave trench, then re-enter the cave almost immediately or in some cases longer. This behavior requires surveyors to be very diligent about tracking both emergences and re-entries throughout the entire survey, which can be extremely difficult in cases of high activity at a particular entrance. Despite these challenges, outflight counts of C. townsendii can be successful for tracking general population trends of maternity groups. Outflight counts of pallid bats (Antrozous pallidus) are also conducted at Lava Beds, and this species is generally easier to count relative to C. townsendii. Though activity is common in the entrance area of pallid bat roosts prior to the actual outflight, once the bats begin to emerge, the majority of individuals generally exit the cave and do not immediately return to the roost. Pallid bats, however, tend to emerge from their roosts fast and low to the ground, requiring a high level of concentration from surveyors during the count.

Ambient Light Conditions

As bats generally emerge from their roosts at varying times after sunset (dependent on species and possibly geographic location), the ambient light level when surveys are conducted creates a significant challenge for completing outflight counts. Surveyors should attempt to position themselves in the best position possible for viewing emerging bats. For some cave entrances, it may be possible to view bats against the horizon as they fly out of the cave; this is not always possible, however, and at Lava Beds. Viewing emerging bats can be especially problematic given their propensity to fly low out of the cave entrances and into the associated trenches, where they are difficult to distinguish from the dark background. The use of night vision instruments (e.g., scopes, goggles) can significantly improve the ability to view bats in low light conditions and may contribute to more successful outflight counts, but surveyors need to ensure that the field of view of the instrument is adequate for viewing the entire cave entrance.

Colony Size

The size of a bat colony will determine what type of outflight count method is used. Small colonies of bats (e.g., < 200 bats) can usually be counted through direct visual observation. Counts of the number of bats exiting a cave and the number of bats re-entering the cave must be recorded for each entrance. These counts can be conveniently recorded using tally counters or "clickers," which allow surveyors to keep their vision trained on the cave entrance for the duration of the outflight. Counts should continue until surveyors are confident that the emergence is over or until it is no longer possible to distinguish bats due to low light. For each cave entrance, the net count is calculated by subtracting the number of bats that re-entered the cave from the number of bats that exited the cave. The final population estimate resulting from this method is then determined by adding together the individual counts from each entrance. These population estimates should be accompanied by a survey description that details outflight behavior, outflight duration, entrance coverage, and any other conditions that may have affected the count. There is no definitive cutoff for the maximum colony size that can be counted through this method, as many factors can influence the feasibility of counts; however, as colony size increases, direct visual counts eventually become impossible due to the column density of emerging bats.

For large bat colonies in the U.S., notably migratory colonies of the Brazilian free-tailed bat (Tadarida brasiliensis), photo estimation using still photography emerged in the 1970s as a promising method for estimating population sizes relative to earlier attempts to visually assess large colonies [McCracken 2003]. Photo estimation methods [Humphrey 1971; Cross 1989] rely on still photographs taken throughout the flight; bats are counted in each photo to determine the average number of bats per frame. This data is combined with measurements of average flight speeds and outflight duration to calculate the estimated population size of the colony. While photo estimation methods are relatively inexpensive and easy to implement, they are susceptible to large margins of error based on data collection resolution and quality [Tobin 2009]. Furthermore, successful counts depend on ideal bat flight behavior and weather conditions and require that outflights begin early enough that the majority of the emergence can be captured while lighting levels allow for photography. With so many variables that are beyond the control of surveyors, it is not uncommon for only a small proportion of photo estimation counts to be determined as successful [Smith 2011]. Currently, the most accurate method for counting large bat populations is thermal imaging using infrared video cameras and computer vision analysis [Betke et al. 2008; Hristov 2010]. Though this technique is highly accurate and repeatable, the associated equipment costs at this time make it impractical for long-term monitoring by most agencies/organizations.

Acoustic Monitoring

The use of acoustic technology for monitoring bats has been in practice for many years, and numerous types of equipment and methodologies continue to emerge. One of the major benefits of acoustic bat monitoring is the ability to detect bat activity on a landscape-scale across multiple seasons; this is particularly advantageous when local bat roosts are either unknown or inaccessible. Another considerable benefit is that acoustic methods are generally non-invasive, allowing for data collection without disturbance to bat populations.

Acoustic monitoring can be used to characterize the occurrence and activity of bat populations, provided that appropriate monitoring methods and sampling design are employed [Gorresen et al. 2008; Rodhouse et al. 2011]. If properly and methodically implemented, acoustic monitoring protocols have the potential to yield datasets capable of establishing baseline occurrence and activity levels, though this may require multiple years of inventory and monitoring to understand natural variance in bat populations. Implementation of long-term acoustic monitoring may be among the best methods for detecting population changes that could result from diseases such as white-nose syndrome (WNS) or from other environmental triggers, natural or otherwise.

This paper does not attempt to provide a review of the many competing devices, companies, and methods that are available for acoustic monitoring of bats. Rather, this section analyzes the advantages and practical applications of two distinct methods of acoustic monitoring: 1) acoustic transect surveys and 2) passive site monitoring.

Acoustic Transect Surveys

Acoustic transects are also known as driving transects, as the most commonly used method [Britzke & Herzog 2010] consists of driving a vehicle at a maintained speed with a roof-mounted bat detector. More broadly though, acoustic transects could be conducted while walking, riding a bike, or using any mode of transportation that lends itself to sampling bat calls along a geographic transect. Transects surveys generally start 30 minutes after sunset and require travel speeds of 20 mph or less to minimize air currents from excessively triggering the bat detector microphone. As with any monitoring effort, designing an effective acoustic transect requires repeatability, so it is best to choose transect routes that are relatively free of traffic lights, noise, or other disturbances that would affect the consistency of the data. Transects that form a loop are ideal for providing lots of options in respect to starting and ending points, which can be varied to increase the range of sample times (relative to sunset) that correspond to locations along the transect. This can also be accomplished along a point-to-point transect by rotating the starting point among either end of the transect and/or by starting the survey at a midpoint, traveling to the end of the transect, and returning to the midpoint (i.e. surveying half the transect twice in a single evening). Transect variations such as these examples can be used on an alternating basis to create a dataset with spatial-temporal diversity, which will increase the ability of the monitoring effort to yield patterns in bat activity.

Developing a site-specific protocol for conducting acoustic transects may be necessary to address logistical issues and establish minimum data collection requirements, such as collection of additional parameters (e.g., temperature, wind speed, moon phase, cloud cover) to supplement bat activity data [Thomas & Weller 2011]. Monitoring efforts should consider the value of collecting data year-round when practical, as year-round datasets will provide the most valuable baseline bat activity dataset for evaluating potential changes in bat populations; additionally, collecting bat activity data during the winter will increase the possibility of early detection of WNS.

Analyzing transect data can be a time consuming aspect of this acoustic method, though software programs exist that considerably lessen the time input required and provide powerful analysis tools. SonoBat software can be used to efficiently process bat calls by scrubbing non-bat recordings and conducting automated species classification. SonoBat also provides a user interface that displays bat calls and allows visual comparison of their shapes and frequencies. For viewing the results of a transect survey, the Transecticizor, a software program from Myotisoft, can be used to spatially plot recordings. This program displays the data from an acoustic transect in Google Earth by linking a GPS tracklog with the time-stamped bat calls recorded during a survey.

Passive Site Monitoring

Passive acoustic monitoring involves the use of an acoustic bat detector or acoustic activity logger to characterize the bat activity at a fixed site, whether it is a known bat roost or a surface location. One of the primary advantages of this type of acoustic monitoring is the ability to collect large amounts of data with relatively little effort. Acoustic devices can be set up at a site and powered by batteries or solar energy for extended periods of time, requiring only periodic visits to download data and/or change batteries.

Monitoring the daily and/or seasonal bat activity of a specific site can be a valuable effort when tracking the activity of a known bat roost. This method can yield data on the daily activity of a colony, such as emergence time, as well as the seasonal use of a bat roost, which can be quite different between seasons when dealing with migratory species or species that select different caves for hibernation vs. maternity use. This type of monitoring can be done with a traditional bat detector (e.g., Pettersson, Anabat), which will involve deploying a detector, usually rigged to a power source and configured on a timer, to record echolocation calls when triggered. This method is invaluable for building a dataset of bat calls that can be identified to some taxonomic level and may aid in determining the specific bat species that is utilizing a roost. If the goal is monitoring a known roost of a known species, however, then the power needs and data processing requirements of a traditional bat detector may be impractical compared to other available methods. A relatively new device, the Bat Logger II, can be deployed for weeks to months, depending on the power source, and logs the bat activity level of a site based on the intensity of ultrasound activity. The Bat Logger II also records temperature and nocturnal light levels. This device does not record actual bat calls and therefore cannot be used to identify bat species using a site. Rather, this device excels at characterizing the daily and seasonal bat activity of a known site. At Lava Beds, this device is being used to document the summer activity of a Brazilian free-tailed bat (Tadarida brasiliensis) roost; the data collected is providing new knowledge on the arrival and departure time of this migratory colony [Thomas 2011b]. Another application of the Bat Logger II at Lava Beds is monitoring a major C. townsendii hibernaculum to establish baseline arousal and activity patterns during the winter.

More broadly, passive acoustic bat monitoring can be implemented through a landscape-scale approach by deploying bat detectors at a number of surface sites across an area. This method has the advantage of recording calls of foraging bats, which are more likely to emit diagnostic calls that can be used in taxonomic identification relative to vocalizations from inside a roost. Also, calls recorded on the surface may be of higher quality than calls recorded inside a roost, where cave walls and surfaces can potentially diminish call quality by creating additional "noise" in the recordings. Detectors can be placed at fixed surface stations throughout the year or can be rotated between stations at designated time intervals to increase spatial sampling diversity. A major benefit of this landscape-scale approach is the potential to adopt consistent monitoring methodology across large regions and pool monitoring data to analyze regional bat activity and trends.

Data Management & Monitoring Protocols

Data collection and data management are crucial components of monitoring and are absolutely critical to the success of any long-term monitoring project. Developing a successful long-term monitoring program entails successfully integrating data collection with data management, and for this reason, it is wise to plan and design data collection procedures in unison with data management strategies. For example, creating an electronic database that corresponds to monitoring methods, and developing a corresponding field data sheet, will help ensure that field data collection is conducted consistently and conforms to the design of the monitoring program. Lava Beds is using a bat database that was recently developed in collaboration with the Pacific Southwest Research Station of the U.S. Forest Service. This database attempts to integrate the breadth of past and current bat monitoring efforts through a series of linked forms and reference tables than can be easily queried to analyze years of bat data. Most importantly, this database was designed to reflect the specific monitoring efforts and priorities of the Lava Beds cave management program, ensuring that it will remain relevant through years of long-term monitoring.

Integrating the monitoring program design with data collection and management efforts can be formalized in bat monitoring protocols. Protocols, when well-designed and easy to follow, allow interchanging personnel to implement monitoring methods over multiple years, a critical component of any successful monitoring program. When developing bat monitoring protocols, cave managers should consider many factors, including the following:

- current knowledge of local bat populations
- monitoring priorities (e.g., significant caves/bat sites, listed species)

- advantages/disadvantages of available bat monitoring efforts
- potential data/knowledge/results to emerge from monitoring
- required time input from staff or volunteers
- startup and recurring equipment/software costs

All of these factors should be considered from a long-term perspective when designing a monitoring program in order to develop an efficient, effective program capable of being implemented for many years.

Conclusion

The bat monitoring methods and recommendations presented in this paper have been described based largely on bat monitoring experience at Lava Beds National Monument, where many of these efforts are being implemented. While regional and national agencies/groups have initiated work to develop standardized bat monitoring efforts, differences in local area habitats and bat populations will likely justify bat monitoring programs that are tailored to specific local needs. Acoustic bat monitoring methods, however, have the potential to follow established procedures and standards to allow for collection of data that can be pooled and analyzed at regional and national levels. Where feasible, cave managers should consider the collective advantages of networking with larger-scale bat monitoring efforts.

Developing a formalized bat monitoring protocol is an effective way of identifying the needs of a long-term bat monitoring program and integrating methods and data standards. A formal protocol, if established as a priority, will provide continuity of monitoring efforts that outlast personnel changes and lead to a long-term dataset capable of establishing baseline conditions and documenting trends in bat populations. Ultimately, a successful bat monitoring program will lend itself to improving bat protection and conservation measures.

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Groundwater Development May Harm National Park Caves

Gretchen Baker
Great Basin National Park

Abstract

Great Basin National Park contains 42 caves, including several that contain ground water, surface water, or both. Caves that are connected to the water table are of special concern to park managers due to a proposed groundwater development project in the area. Southern Nevada Water Authority plans to pump substantial amounts of water from the two valleys adjacent to the national park. Although the park is over 1,500 feet higher than the valley floor, the USGS has conducted a study that shows park resources, including caves, could be impacted. Additional studies have shown the likelihood of interconnection between the valley-floor aquifer and the water under the caves. Changes in water levels under caves have the potential to alter cave-forming processes and impact the ecology of the caves. Several endemic species make park caves their home, so this is of great concern to park managers. The park has commenced biological, temperature, and water level inventory and monitoring to develop a baseline dataset of cave conditions. In addition, the park has worked to communicate the fragility of these cave ecosystems to those responsible for making decisions with regards to this project.

The Effects of Evapotranspiration Upon Recharge Using the Stable Isotopes of Oxygen and Hydrogen in the Carbonate Aquifers of the Cumberland Plateau in Southeast Kentucky

Lee J. Florea, Department of Geological Sciences,
Ball State University, Muncie, IN 47306
lflorea@bsu.edu

Abstract

In this brief manuscript, we consider the variation of the stable isotopes of oxygen, $\delta^{18}O$, and hydrogen, $\delta^{2}H$, in samples collected during 2010 and 2011 from precipitation and shallow groundwater along the Cumberland Plateau of southeast Kentucky. These data from the 1,900-ha Redmond Creek karst aquifer lend insight into the source and timing of recharge to shallow groundwater in the epigenic karst of the U.S midcontinent. Specifically, we find that only 43% of precipitation remains as potential recharge after accounting for evapotranspiration, and 85% of this potential recharge occurs during only four two-week sampling periods. The isotopic composition of precipitation samples, which fluctuate seasonally according to temperature, are more variable than the composition of shallow groundwater, which remains nearly constant. The deuterium excess of these precipitation samples reflects moisture sources during the winter months more influenced by contributions from re-evaporated, continental moisture. When weighted for potential recharge, our stable isotope data in precipitation indicate a similarity with the mean values of shallow groundwater, suggesting a recharge threshold linked to evapotranspiration.

Introduction and Study Area

Not all precipitation recharges an aquifer. Of particular relevance to this manuscript is the concept of a 'threshold' for recharge to a karst aquifer, called 'selective recharge' by Kendall and Doctor (2011). In particular, we note that recharge in karst may involve both a discrete, 'quick flow' component requiring enough rainfall to generate overland flow to a karst feature (Jones et al., 2000), and diffuse recharge through the epikarst and rock matrix. Florea and Vacher (2007) noted both discrete and diffuse components during a study in Briar Cave Florida as a regional rise in the water table of the Floridan aquifer immediately following major hurricanes in 2004 followed by a delayed increase in the drip rate from the rock matrix. The component of diffuse recharge to a karst aquifer is potentially very low. For example, Jones and Banner (2003), in reference to a study in Barbados, make the following statement about tropical karst aquifers: "without such [discrete] transport, it is likely that the rainwater will be taken up by evapotranspiration" (Jones and Banner, 2003, p. 131). Using stable isotopes of oxygen and hydrogen, they conclude that, for Barbados, monthly rainfall must exceed a threshold of 19.5 cm. Florea and Vacher (2007) further generalize for places such as Florida and Barbados by stating:

> [I]t cannot be assumed that a rainy season… equates to a recharge season. If seasonal variation of temperature and thus potential evapotranspiration are also significant, the rainy season will coincide with the high potential evaporation season. Both derive from the high-sun season (Florea and Vacher, 2007, p. 445).

This short paper explores some of these same concepts in the karst of southeast Kentucky and, like Jones and Banner (2003), uses the stable isotopes of oxygen and hydrogen to elucidate information about the sources of moisture and the nature and timing of aquifer recharge.

The Cumberland Plateau

The data for this study come from the Cumberland Escarpment in southeast Kentucky. The topography of the study area is split equally between uplands of the Cumberland Plateau and deeply incised valleys that drain those uplands. The terrain of the escarpment is rugged, with upper slopes lined with vertical cliffs of Pennsylvanian sandstones and conglomerates of the Lee Formation, a 'bench' of gentle slopes marking the exposure of transitional-marine calcareous shales that comprise the upper-Mississippian Paragon Formation, and lower slopes and sinkhole floors underlain by the relatively pure carbonates of the middle-Mississippian Slade Formation (Ettensohn et al., 1984). Relief in the study area exceeds 300 m with ridge tops above 530 m and valley floors below 300 m.

Karst Geology and Hydrology

The Slade Formation, regionally divided into the St. Louis, the Ste. Genevieve, and Kidder Limestone members, is significantly modified by solution activity and karst landscapes dominate the area of carbonate exposure (Simpson and Florea, 2009). Underlying, and less soluble cross-bedded siltstones of the Salem-Warsaw Formations locally act as a base for conduit development. Sinkholes and other closed drainage features prevail within incised valleys. Vertical solution shafts occur in stress release fractures along the hillsides (Ferguson, 1967) near the contact with overlying siliciclastics and capture allogenic recharge from the plateau surface (Brucker et al., 1972). In the classic epigenetic model, vadose drainage through caves follows a stair-step pattern through the strata of the plateau margin (Crawford, 1984) and coalesces into sinuous base-level conduits that generally parallel the surface valley and topographic contours (Sasowsky and White, 1994). Tiers of these horizontal passages formed in response to episodic changes of base level controlled by the advance and retreat of the Laurentide ice sheet (Anthony and Granger, 2004). Aquifer storage is concentrated in the rock matrix; however, the low permeability of these limestones ensures that the communication between the matrix and the cave passages is low. Therefore, springflow hydrographs are 'flahsy' (Florea and Vacher, 2006; White, 1988) with most longer-term storage lingering within the epikarst.

Climate

The Köppen climate classification of the study area is humid subtropical (Peel et al. 2007). Average seasonal temperatures available from The National Climatic Data Center (NCDC - http://www.ncdc.noaa.gov/oa/ncdc.html) range from 24°C in July to 0°C in January with summer maximum and winter minimum average temperatures of 30°C and -5°C, respectively. Average annual precipitation is 130 cm and has a seasonal component weighted toward wintertime and springtime rainfall with monthly average maxima of 13 cm in May and minima of 7.5 cm in October. Precipitation is primarily characterized by frontal systems entrained by Rosby waves and mesoscale convective events during the spring and early summer. During the summer and fall, comparatively more moisture from the Gulf of Mexico is entrained into these frontal systems than during the winter.

We can thus generalize, *a priori*, that the stable isotopes of oxygen and hydrogen of precipitation in southeast Kentucky will be weighted toward, or enriched in, the heavier isotopes during the warmer summer months and depleted in these same heavier isotopes during the cooler winter months. In other words, we should see a 'temperature effect', one of the Rayleigh fractionation processes that impact the isotopic composition of atmospheric moisture (Dansgaard, 1964). Similarly, we should expect a 'continental effect', where the degree of depletion of the heavier isotope in precipitation is tied to the distance to the source of the atmospheric moisture (Dansgaard, 1964). In other words, storm events with moisture derived from the Gulf of Mexico will be more enriched in the heavier isotope than storm events dominated by moisture of a Pacific origin.

Solar insolation tracks a combination of cloud cover, which is at a maximum in the winter and a minimum in the fall, and sun position, at a maximum during the summer solstice. Whereas averages of solar insolation in December are around 215 Cal/cm^{2}day, averages during June though August can exceed 400 Cal/cm^{2}day (data available from the National Renewable Energy Lab, http://www.nrel.gov/, and based upon model by Perez et al. 2002). Using a Priestly-Taylor PET model, these generalized data for solar insolation and temperature translate into minimum and maximum values of PET for the study area of 0.2 cm/day during the winter and more than 0.7 cm/day during the summer.

Redmond Creek

The data for this study come from the Redmond Creek karst aquifer, comprising some 15 km of surveyed passage and 45 known cave entrances along the Cumberland Escarpment near the Tennessee border in Wayne County, KY (Figure 1). All water in Redmond Creek is inferred to drain form the overlying siliciclastic caprock and through short caves in the Bangor limestone, such as Stream Cave (SC – Walden et al., 2001) before ultimately sinking into the Kidder limestone. At this point, the subsurface water progresses toward the north end of a massive sinkhole (some 6.6 km in the long dimension) and reappears at Natural Bridge Caverns (NBC) as the headwaters of Otter Creek, a tributary of the Cumberland River (Simpson and Florea, 2009).

In normal and low water conditions, flowing water is only minimally evident in the caves of Redmond Creek. Water that rises within NBC upwells from phreatic passages, thus the bulk of the water discharging from NBC between floods must therefore derive from undiscovered cave passages below the level of Redmond Creek Cave or from within the alluvium in the floor of the sinkhole, or both. In fact, recent geophysical data collected using electrical resistivity tomography (Florea et al., 2011) suggest that the alluvium underlying the sinkhole floor at Redmond Creek may exceed 30-m in depth.

Samples and Methods

Data for $\delta^{18}O$ and δ^2H come from 16 sets of bi-monthly samples collected between July 2010 and February 2011. Samples were collected in 60 mL glass bottles, sealed and stored at 4°C until time of analysis. Grab samples from SC and NBC were filtered through a 0.45-μm membrane. Samples of precipitation represent a two-week average collected at within the watershed (Figure 1) using a funnel, a tube, and a 20-L HDPE carboy with a layer of mineral oil to prevent evaporation of the sample. During two sampling periods (mid September and early November) limited precipitation yielded no sample. Analyses for the isotopic ratios of oxygen and hydrogen, $\delta^{18}O$ and δ^2H, were conducted in the Isotope Geochemistry Lab at the University of South Florida using a Delta V gas-source Isotope Ratio Mass Spectrometer (IRMS) coupled to a Gasbench II peripheral [Thermo-Finnigan] using the method by (Lai et al., 2006) and standardized to VSMOW using the following relation for oxygen

$$\delta^{18}O = \frac{\delta^{18}O_{sample} - \delta^{18}O_{VSMOW}}{\delta^{18}O_{VSMOW}}.$$

Published errors for $\delta^{18}O$ and δ^2H are given as ±0.1‰ and ± 0.5‰, respectively.

Daily values of precipitation and average temperature were computed from data collected every quarter hour via an ONSET Micro Station linked to a model RG2-M tipping bucket rain gauge and a S-THB-M002 temperature/RH sensor. Approximate values of daily solar insolation were obtained from an Apogee CS300 PYR-P pyranometer operated by the Kentucky Mesonet (http://www.kymesonet.org) at a weather station near Albany, KY (Latitude: 36.71ºN Longitude: -85.14º)

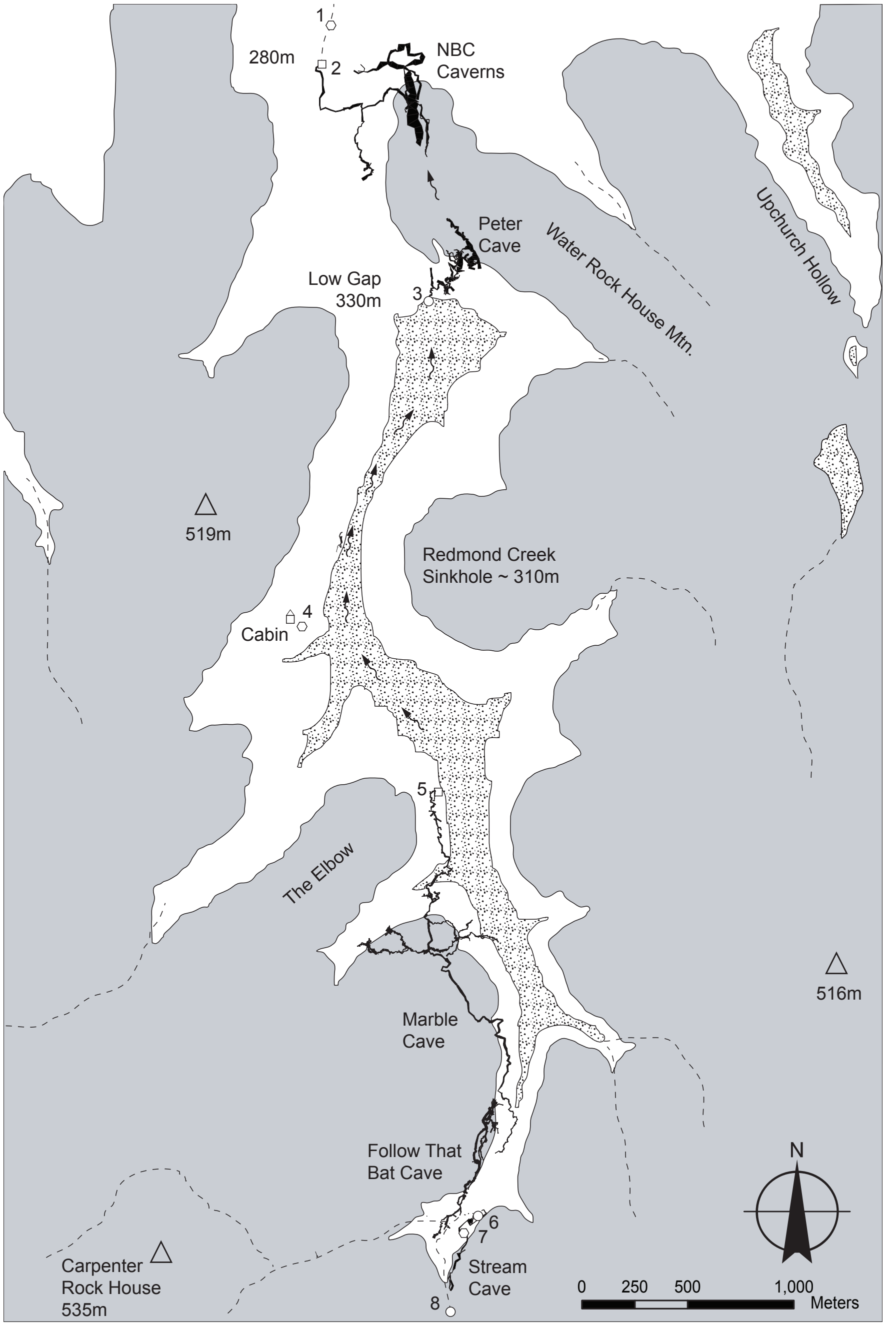

Figure 1. The Redmond Creek karst aquifer in southeast Kentucky. Grey areas are underlain by siliciclastics of the Pennsylvanian-age of the Lee and Breathitt Formations and Mississippian-age Paragon Formation, white areas are underlain by Mississippian-age carbonates of the Slade Formation, and thick deposits of Quaternary alluvium underlie the stippled region. Solid black lines indicate surveyed cave passages and inferred groundwater flowpaths are designated by dashed arrows. Dashed lines are ephemeral, first-order tributaries. 1) Monitoring site, 2) Natural Bridge Caverns spring, 3) north sinkpoint, 4) weather monitoring station, 5) Marble Cave overflow spring, 6) main Redmond Creek sink, 7) Stream Cave spring, 8) Upstream sink.

some 21-km distant from Redmond Creek. By using published tables, daily average temperature data provide values of water density and kinematic viscosity, and when combined with solar insolation data, the Priestly-Taylor model provides an estimate of daily PET using the following equation

$$PET = 1.26\alpha \frac{[Q_n/\rho\lambda]}{\alpha+1},$$

a method valid to 95% in humid regions with low moisture stress that depends only upon knowledge of average daily temperature and solar insolation. In this model, *PET* is the potential evapotranspiration, α is the Penman ratio, Q_n is the solar insolation in Cal/cm^2-day, ρ is the fluid density, and λ is the fluid viscosity (Priestley and Taylor, 1972). The Penman ratio, the fluid density, and the fluid viscosity are each a function of the measured temperature.

Using our daily precipitation data (P) and our modeled values of daily PET, we compute potential recharge (R) for each sampling period using the following logical statement

$$If\ P > PET, ten\ R = P - PET, else\ R = 0\ .$$

By using this statement, we assume that recharge to the aquifer is not removed when PET exceeds precipitation for that sampling period.

Results and Discussion

In the most general terms, the data from this study reveal the timing and nature of recharge in the karst aquifers of the Cumberland Plateau. Secondarily, they characterize the moisture sources of precipitation in this region. The first is important from a hydrogeological perspective. The second can help us deduce trends in climate and calibrate paleoclimate studies. Both are important in this part of Appalachia where some residents still rely on water from karst springs as a source of domestic water.

The Stable isotope data for $\delta^{18}O$ and $\delta^{2}H$ at SC, NBC, and precipitation samples are provided in Figure 2 and alongside average temperature, precipitation, PET, and potential recharge for the sampling period. Our results reveal that of the 110 cm of precipitation that fell during our monitoring period, only 43% (47 cm) became potential recharge. Interestingly, four sampling periods (7/20/2010, 8/31/2010, 12/7/2010, and 12/21/2010) account for 54% of the total precipitation and 85% of the potential recharge to the watershed. Mean values of $\delta^{18}O$ and $\delta^{2}H$ at SC (-7.23‰ ± 0.19‰ and -40.87‰ ± 2.24‰) and NBC (-7.28‰ ± 0.16‰ and -40.84‰ ± 1.24‰) are similar and more stable than values obtained from the weighted samples of precipitation (-6.52‰ ± 0.39‰ and -35.42‰ ± 2.16‰).

These isotope data reveal the importance of evapotranspiration. Only some precipitation events result in recharge. In Figure 3, this dependence of $\delta^{18}O$ with respect to precipitation and potential recharge are explored. The $\delta^{18}O$ data at SC and NBC are stable regardless of precipitation amount or potential recharge. For the precipitation samples, no trends are present in the $\delta^{18}O$ data when compared to precipitation amount. However, comparing the $\delta^{18}O$ data from precipitation samples with potential recharge reveals a similarity with the data from SC and NBC (Figure 3). The implication is that the groundwater in the Redmond Creek karst aquifer is weighted to recharge from significant storm events, such as a storm event on 8/19/2010 that contributed 12.8 cm in one day, and more generally during periods in the winter where solar insolation is low (Figure 2). This recharge, likely stored within the thick alluvium below the sinkhole floor, provides the relatively stable isotopic values measured at NBC, regardless of the season (Figures 2 and 3).

Figure 4 presents the global meteoric water line (GMWL) and the best-fit local meteoric water line (LMWL) of our $\delta^{18}O$ and δ^2H results for precipitation – $\delta^2H = (7)\ \delta^{18}O + 10.5‰$ ($R^2 = 0.96$). Samples of shallow groundwater from SC and NBC cluster at the midpoint of our precipitation data and are a signature of the precipitation events identified in Figures 2 and 3 that recharge the shallow groundwater. All data are shifted more than +10 ‰ above the GMWL (Figure 2) and reflect moisture sources more influenced by contributions from cooler, dryer air masses (Merlivat and Jouzel, 1979). As with $\delta^{18}O$ and δ^2H, values of D_{ex} at both SC (17.36‰ ± 1.16‰) and NBC (16.95‰ ± 1.24‰) represent similar populations. Precipitation-weighted D_{ex} (16.75 ± 1.24‰) is also similar to both SC and NBC.

Temperature dependence upon $\delta^{18}O$, δ^2H, and D_{ex} data are shown in Figure 5. For $\delta^{18}O$ and δ^2H, the precipitation data are directly proportional to average temperature ($R^2 = 0.43$ and 0.34, respectively) demonstrating the temperature effect upon isotope fractionation in precipitation (Dansgaard, 1964). In contrast, precipitation D_{ex} is inversely proportional to average temperature ($R^2 = 0.43$) suggesting that the moisture source for precipitation during the cooler, winter months contains contributions from re-evaporated, continental moisture (Merlivat and Jouzel, 1979). Interestingly, no proportional relationships with temperature are present in the isotope data at SC and NBC, again illustrating the stability of oxygen and hydrogen isotopes in shallow groundwater, although samples between 4°C and 15°C tend to be the most enriched in the heavier isotope (Figure 4).

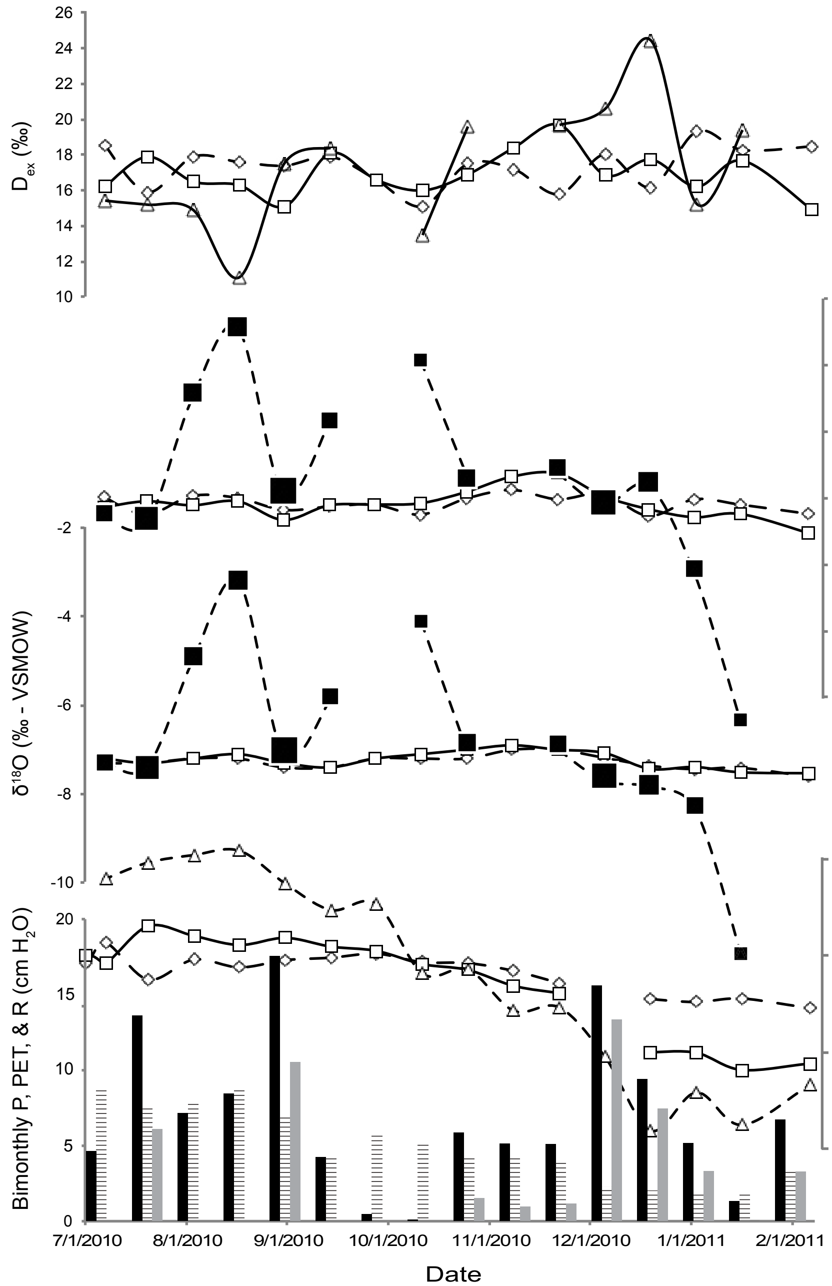

Figure 2. Temperature and stable isotope data for oxygen, hydrogen, and deuterium excess from precipitation (black squares and triangles), Stream Cave (diamonds), and Natural Bridge Caverns (open squares) alongside precipitation (black vertical bars), potential evapotranspiration (hachured vertical bars), and potential recharge (grey vertical bars). The relative sizes of the black squares for precipitation are proportional to the magnitude of precipitation for that sampling period.

Summary Remarks

These data from southeast Kentucky are among the first published data on stable isotopes in precipitation and shallow groundwater from this region. As such, they are a useful baseline for future hydrologic, geochemical, and paleoclimate investigations because they help outline the source and timing of recharge to shallow groundwater in the epigenic karst of the U.S midcontinent; shallow groundwater still used by many as a source of domestic water.

Recharge is weighted toward large and infrequent storm events that exceed a threshold determined, in part, by evapotranspiration. In this study, 43% precipitation remains as potential recharge and 85% of this potential recharge occurs during only four two-week sampling periods and likely from five individual storms events. Three of these events are during the cooler winter months, attesting to recharge during periods of lower solar insolation. The deuterium excess of this winter precipitation is greater than during the summer and reflect moisture sources more influenced by contributions from re-evaporated, continental moisture. All five likely recharge events have similar isotopic composition. As a result, the isotopic signature of shallow groundwater remains stable throughout the course of this study even though the values in rainfall fluctuate seasonally according to temperature.

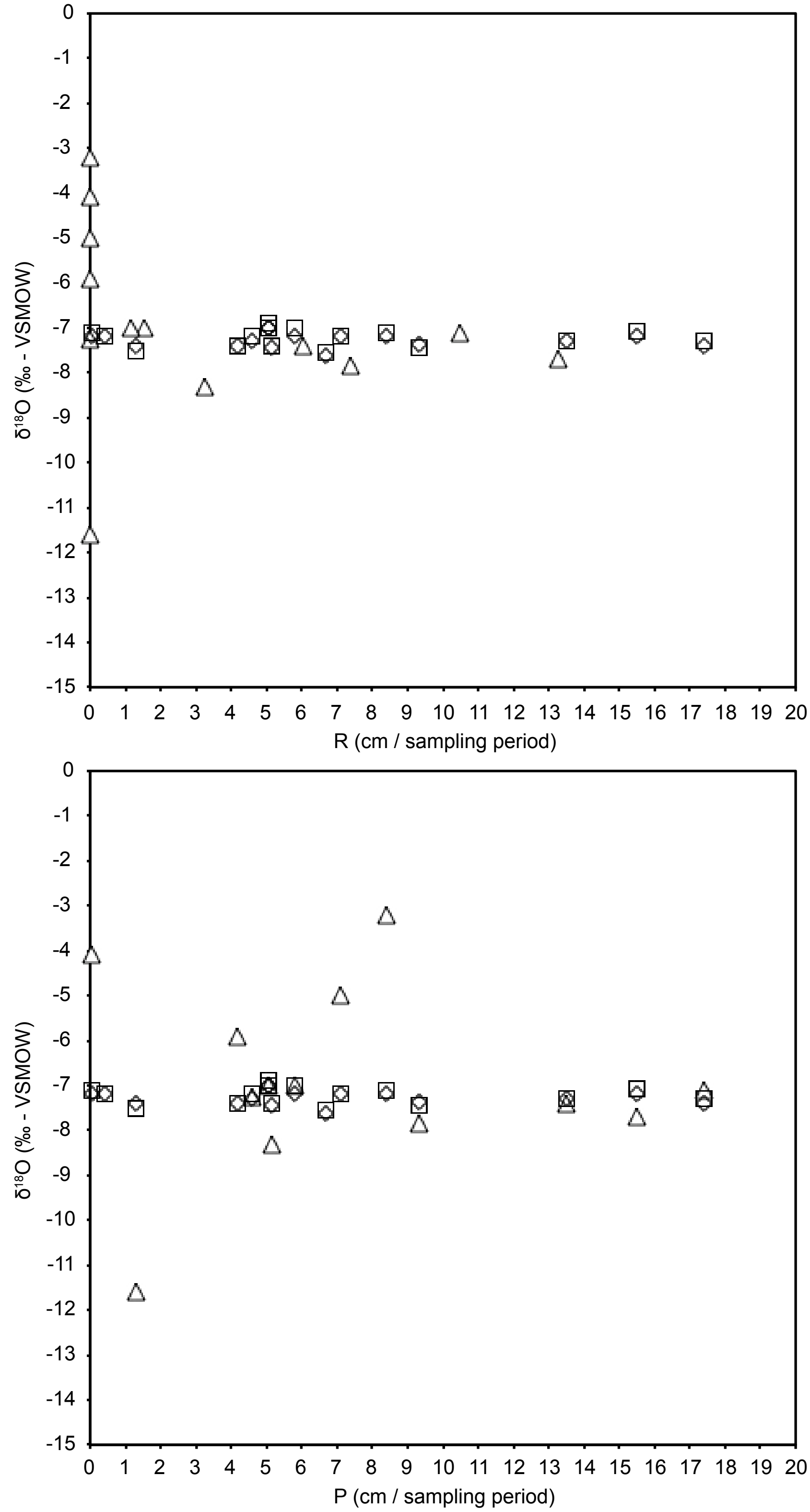

Figure 3. Stable isotope data for oxygen from precipitation (triangles), Stream Cave (diamonds), and Natural Bridge Caverns (open squares) compared against precipitation (P- bottom) and potential recharge (R – top).

Acknowledgments

The author is indebted to the hard work and dedication of fellow caves and colleagues during this study. In particular, I would like to acknowledge the major contributions by Bill Walden, Chasity Stinson, and Nick Lawhon. I also welcome the conversations, hospitality, and access provided by landowners Tim Pyles and Kay Koger and cavers Rick Gordon, Deb Moore, Harry Gopel, and Eric Weaver. Finally, I appreciate the collaborations with Jonathan Wynn and the USF Stable Isotope Laboratory on this and other projects. Funding for this work was provided by a WKU Provost Incentive grant, a WKU start-up index, and a Ball State University start-up package.

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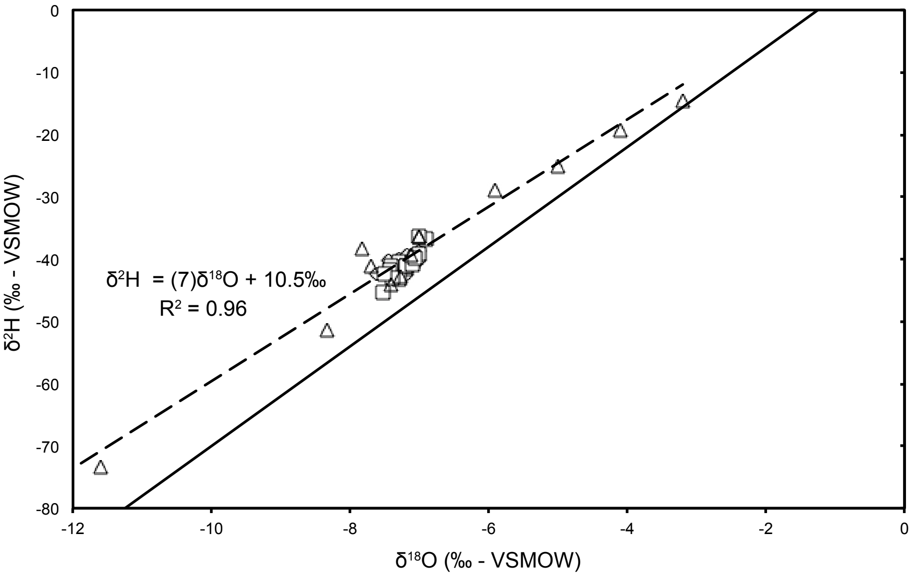

Figure 4. Stable isotopes of hydrogen compared against oxygen for precipitation (triangles), Stream Cave (diamonds), and Natural Bridge Caverns (open squares). The solid line represents the Global Meteoric Water Line (GMWL). The dashed line is the best-fit Local Meteoric Water Line (LMWL) for the available precipitation data.

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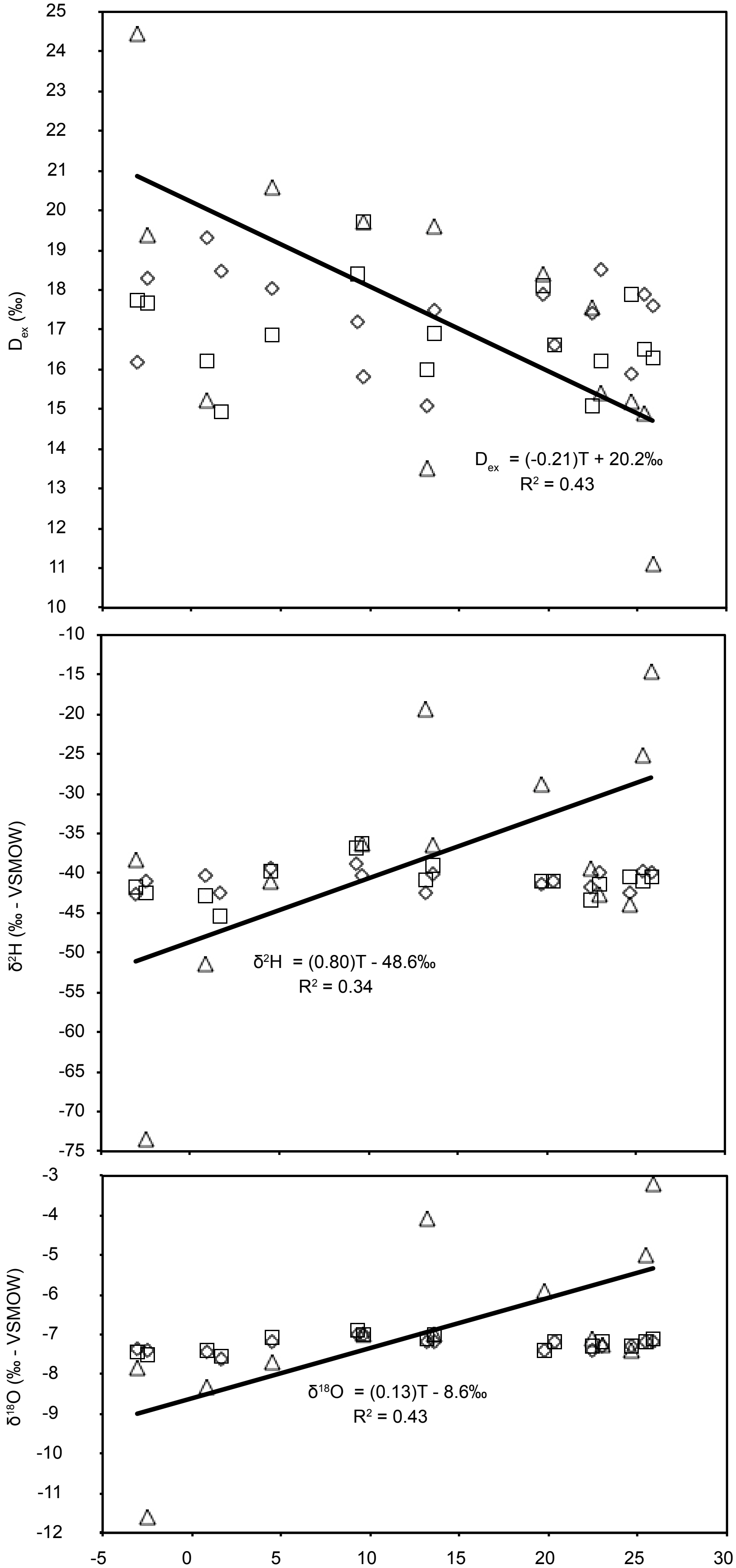

Figure 5. Stable isotope data for oxygen, hydrogen, and deuterium excess from precipitation (triangles), Stream Cave (diamonds), and Natural Bridge Caverns (open squares) compared against temperature. Solid lines are best-fit regressions for the precipitation data.

The Relationship of Recent Geologic Features to the Origin of Jewel Cave

Mike Wiles
Jewel Cave National Monument
11149 U.S. Highway 16
Custer, SD 57730
mike_wiles@nps.gov

Abstract

Recent studies have documented several unexpected relationships between cave features and surface geology. The most striking observation is the fact that Jewel Cave exists almost exclusively in limestone capped with the Minnelusa Formation. This relationship holds throughout the southern Black Hills and, without exception, no cave over 300 feet in length is known to exist within uncapped limestone. Furthermore, there is no mappable paleotopographical relief within the Jewel Cave Quadrangle. Rather, evidence within Jewel Cave strongly suggested that "paleofill" deposits formed contemporaneously with the development of the cave – <u>after</u> lithification of the basal Minnelusa sandstone.

Finally, ellipsoidal clasts have been mapped across more than 100 square miles north of Jewel Cave. They were deposited contemporaneously with the development of the present-day topography; however, they also occur at two locations <u>within</u> Jewel Cave. Both are in close relationship with basal Minnelusa material, and one is sandwiched between a "neofill" deposit and the cave's ubiquitous calcite spar coating – yet they are beneath over 200 feet of non-cave-bearing rock, with no likelihood of nearby cave entrances.

These observations demonstrate a strong correlation between the passages of Jewel Cave and modern geological features. The evidence suggests that Jewel Cave formed as a result of the most recent processes that shaped the present-day stratigraphy, structure, and topography. This gives pause for reevaluation of the origin of Black Hills caves.

Introduction

Over the last 20 years, exploration and mapping of Jewel Cave, as well as geological mapping of the Jewel Cave Quadrangle, have documented several unexpected relationships between surface and subsurface features in the southern Black Hills; and also within and between the Pahasapa Limestone and Minnelusa Formations themselves. Those observations ultimately require a rethinking of the nature and timing of the geological events responsible for the origin of the caves of the Black Hills – especially Jewel Cave. This paper presents several of these observations in order to encourage further study.

Topography

Since the 1930s, most geological studies have depicted the caves of the Black Hills as having formed previous to, and independent of, the events that shaped the modern landscape. According to this view, cave entrances only exist where down-cutting streams randomly intersected underlying cave passages. Jewel Cave, however, shows a clear correlation between the pattern of passages and the modern-day topography (Figure 1). Beneath the hillsides the cave consists of a complex maze of large passages; but there are significantly fewer passages near the canyons, and their size and complexity are markedly diminished. If the canyons had randomly cut into the limestone long after the era of cave development, this would have created a dissected maze with multiple entrances; and there should be at least a few instances where erosion has removed a passage, but remnant continuations still exist on both sides of a canyon. However, these cross-cutting relationships do not exist, nor is there evidence of stream deposits or related organic material intruding from the surface. Jewel Cave has only one known natural entrance, which was originally too small for human entry. Taken together, these observations suggest that the hydrologic regime that formed the cave was influenced by the surface hydrology, and that the two were happening concurrently.

Geologic Contacts

An even more surprising relationship can be seen between the caves of the southern Black Hills and the geologic contacts (Figure 2). The entrances of the large caves in the southern Black Hills are all found at the contact between the Pahasapa Limestone and the Minnelusa Formation, and the passages themselves lay almost exclusively beneath the Minnelusa. What's more, Figure 2 also a shows large area of exposed Pahasapa, where the overlying Minnelusa has been erosionally removed. The strange thing is that this area contains no large cave systems, such as those found beneath the Minnelusa cap. In fact, none of the caves in the uncapped limestone is more than 300 feet long! While it seems obvious that the Minnelusa cap is somehow responsible for the development of the large caves, an important question remains: The Minnelusa originally covered the areas of exposed Pahasapa, and was erosionally removed during the uplift of the Black Hills; so why don't large caves (or at least

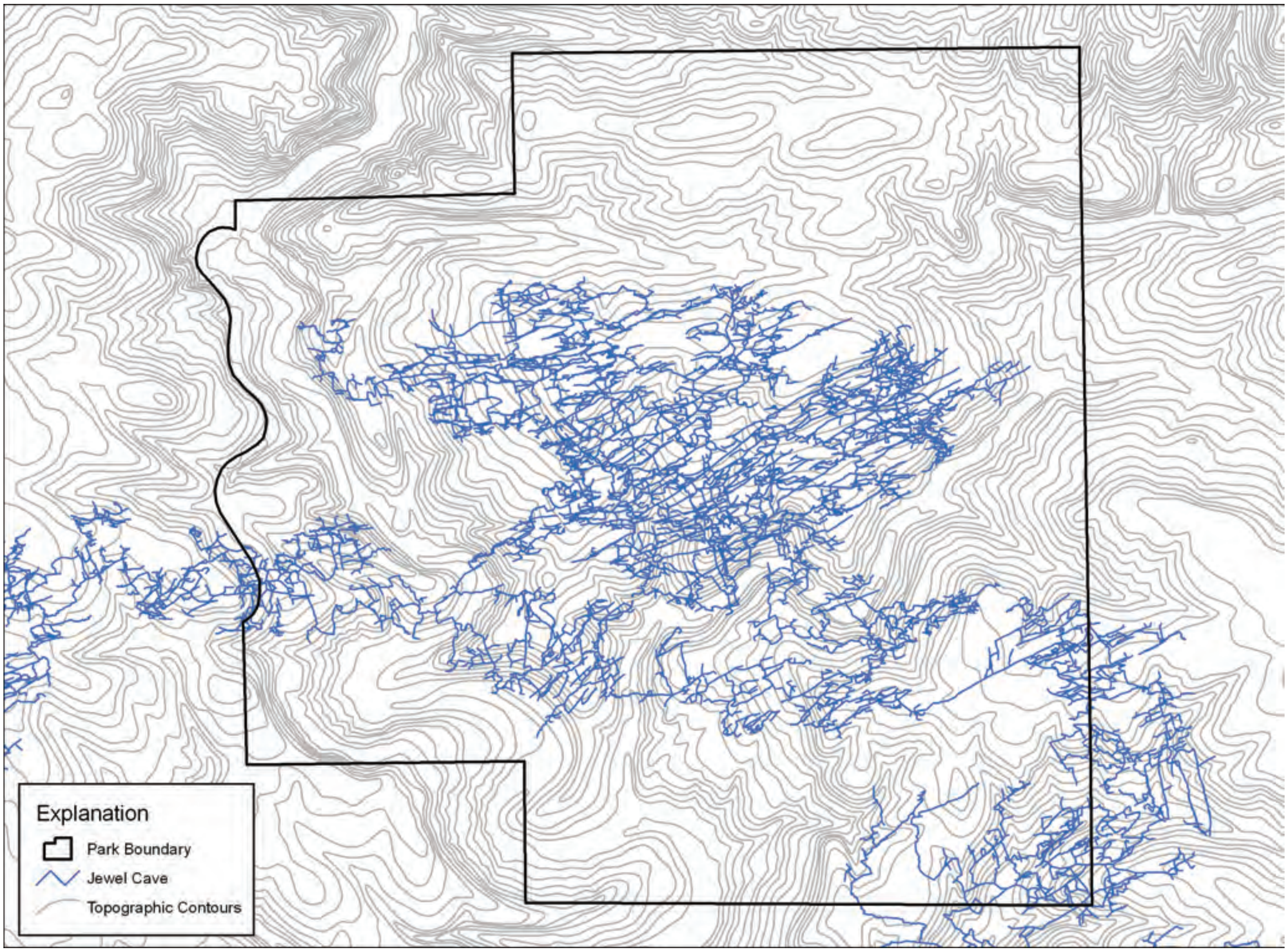

Figure 1. Relationship between Jewel Cave and the surface topography

remnants) exist in that area too? Consistent with the relationship between Jewel Cave and the overlying topography, it appears that significant cave development began fairly recently – near the end of the last episode of uplift, when the accompanying erosion was bringing the geological contacts into their present configuration.

Cave Fill

Black Hills caves often contain "paleofill," which is believed to have originated when an early-Pennsylvanian sea transgressed over a preexisting paleokarst topography, which had formed at the top of the Pahasapa. This would have occurred over 300 million years ago. However, some passages within Jewel Cave reach up toward the Minnelusa and contain blocks of lithified, cross-bedded sandstone (see Figure 3). This sandstone is identical to that found at the base of the Minnelusa where exposed in nearby road cuts. The fact that the cave fill contains lithified pieces of the basal Minnelusa indicates that dissolution of the passage occurred *after* the deposition and lithification of the Minnelusa. The evidence suggests that the fills occurred geologically recently, as portions of the basal Minnelusa collapsed into cave passages, concurrently or just after their dissolution. If this interpretation is correct, then the fill deposits are more accurately described as "neofill" rather than "paleofill."

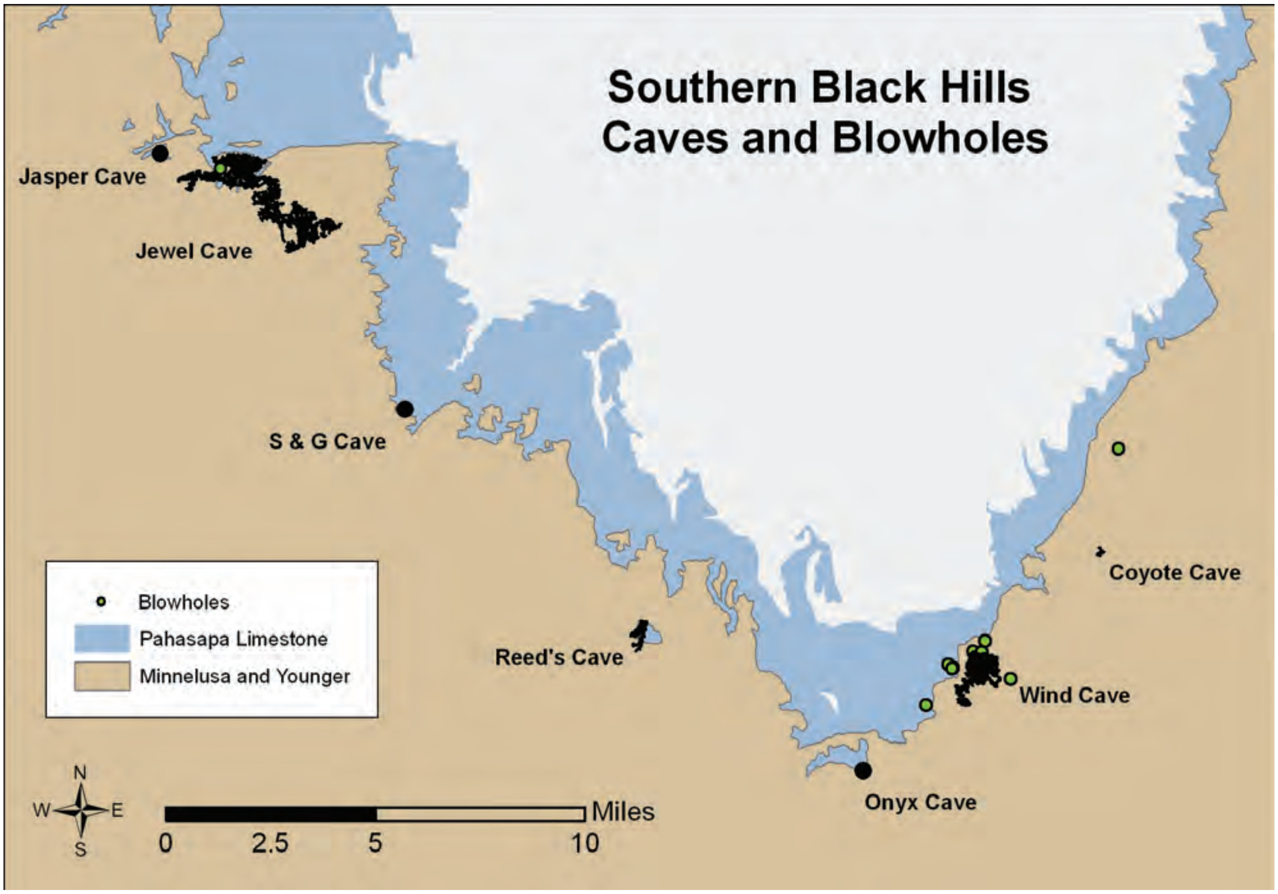

Figure 2. Relationship between large caves and the geological contacts

Figure 3. Lithified blocks of basal Minnelusa sandstone sandstone within Jewel Cave

Geological Structure

Jewel Cave's passages form a pattern with distinct linear discontinuities, many of which have been found to correlate with faults and lineaments (Figure 4), and some of which can even be seen in aerial and satellite photos. The entire known cave is located south of the Jewel Cave Fault (not shown), which is best characterized as a fault *system*. The cave crosses several secondary faults with displacements ranging from 2 to 40 feet. However, the passages do not seem to be offset by the faults. Instead, the faults appear to predate the cave. For example, there is nearly 40 feet of stratigraphic displacement between the *Delicate Arch Room* and the *Miseries*, but they are connected by a nearly horizontal crawl known as the *Dugway*. Additionally, Jewel Cave's only natural entrance is located precisely at the crest of a broad anticline (Figure 4) along with the cave's only known paleontological fill – located in the entrance room. All these features indicate that the geologic structure predates the cave development, and point toward a geologically recent origin of Jewel Cave.

Stratigraphy

Geologic mapping has defined six subunits of the Minnelusa formation (Table 1). The thickness of each subunit is virtually constant, which aided in mapping even subtle structures. Because of this knowledge, Wiles (in Fagnan, 2002) concluded that there is no mappable paleokarst topography within the Jewel Cave quadrangle.

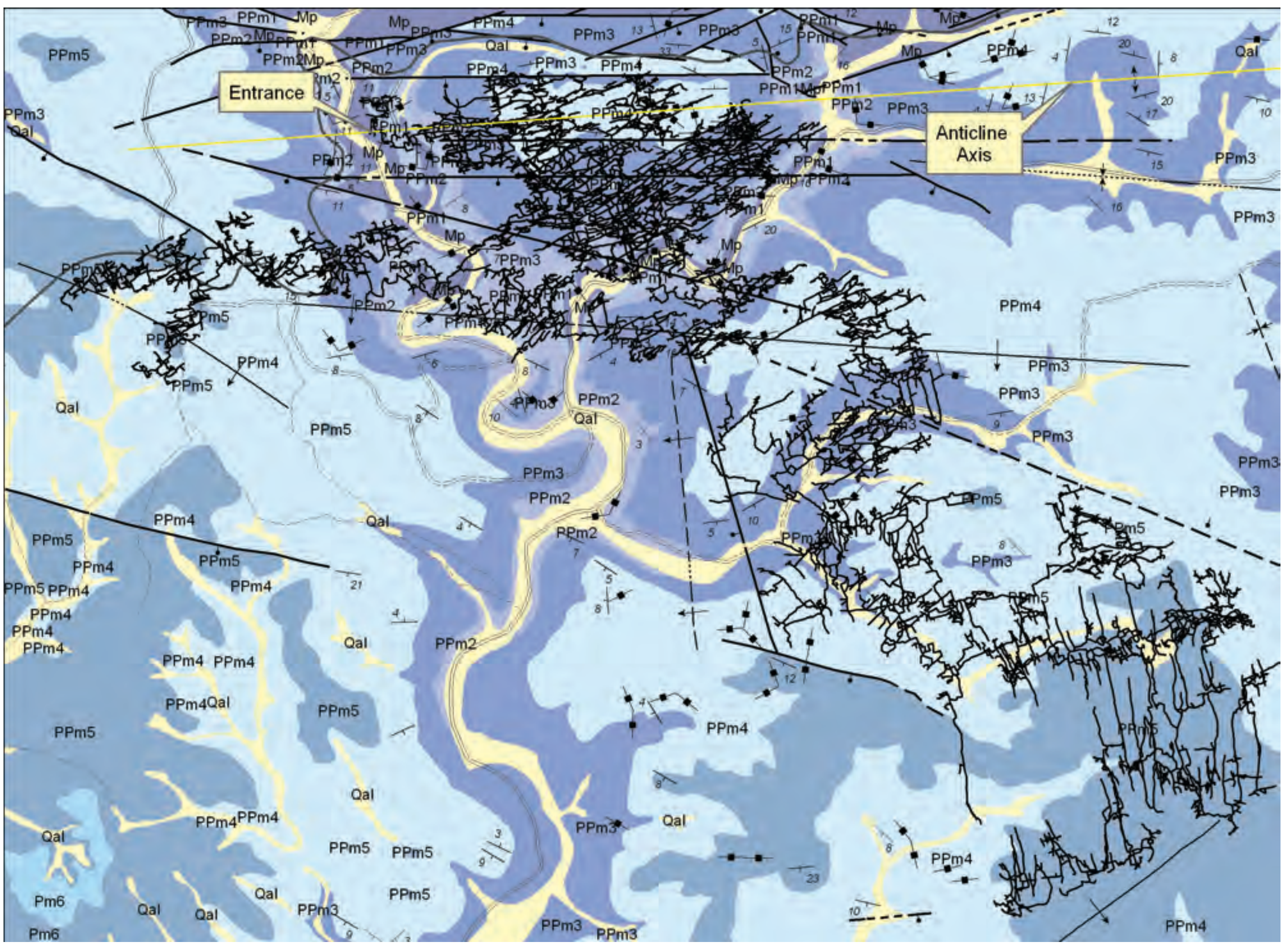

Figure 4. Relationship between Jewel Cave and geologic structures (after Fagnan, 2002)

Subunit	Abbreviated description	Thickness
VI	brecciated sandstone, limestone, and anhydrite	n/a
V	varicolored sandstones	120 feet
IV	interbedded dolomite and sandstone	120 feet
III	sandstone with limestone cap	120 feet
II	thin bedded cherty limestone	50 feet
I	cross-bedded sandstone and thickness compensatory red siltstone	40 feet

Table 1. Stratigraphy of the Minnelusa Formation (after Davis and Wiles, 2006)

Most of the previously reported paleotopographic relief was the result of misidentification of limestone units; besides the Pahasapa limestone, there are two prominent limestone subunits within the overlying Minnelusa. For example, Figure 5 shows the contact between subunit I and subunit II of the lower Minnelusa formation. Subunit I consists of sandstone with a thickness-compensatory layer of red siltstone, overlain with basal limestone of subunit II. The red siltstone component ranges from zero to at least 15 feet in thickness.

Reinterpretation of a "Paleokarst" Feature

Figure 6 shows a feature in a road cut along U.S. Highway 16, which has previously been interpreted as a paleo-sinkhole within the Pahasapa limestone. However, the limestone in the foreground is not the Pahasapa limestone at all. It is the limestone of subunit II, within the Minnelusa. It is the downthrown side of a fault. The foreground is separated from the background by a vertical fault plane with around 20 feet displacement. The background is the relatively upthrown block, and includes the contact between the basal limestone of subunit II and the red siltstone of subunit I. Much of the limestone in the downthrown block (foreground) was removed during road construction in the mid-1930s. Since then, the

Figure 5. Subunits I and II. Dotted line indicates the contact between the thickness-compensatory sandstone and red siltstone components of subunit I

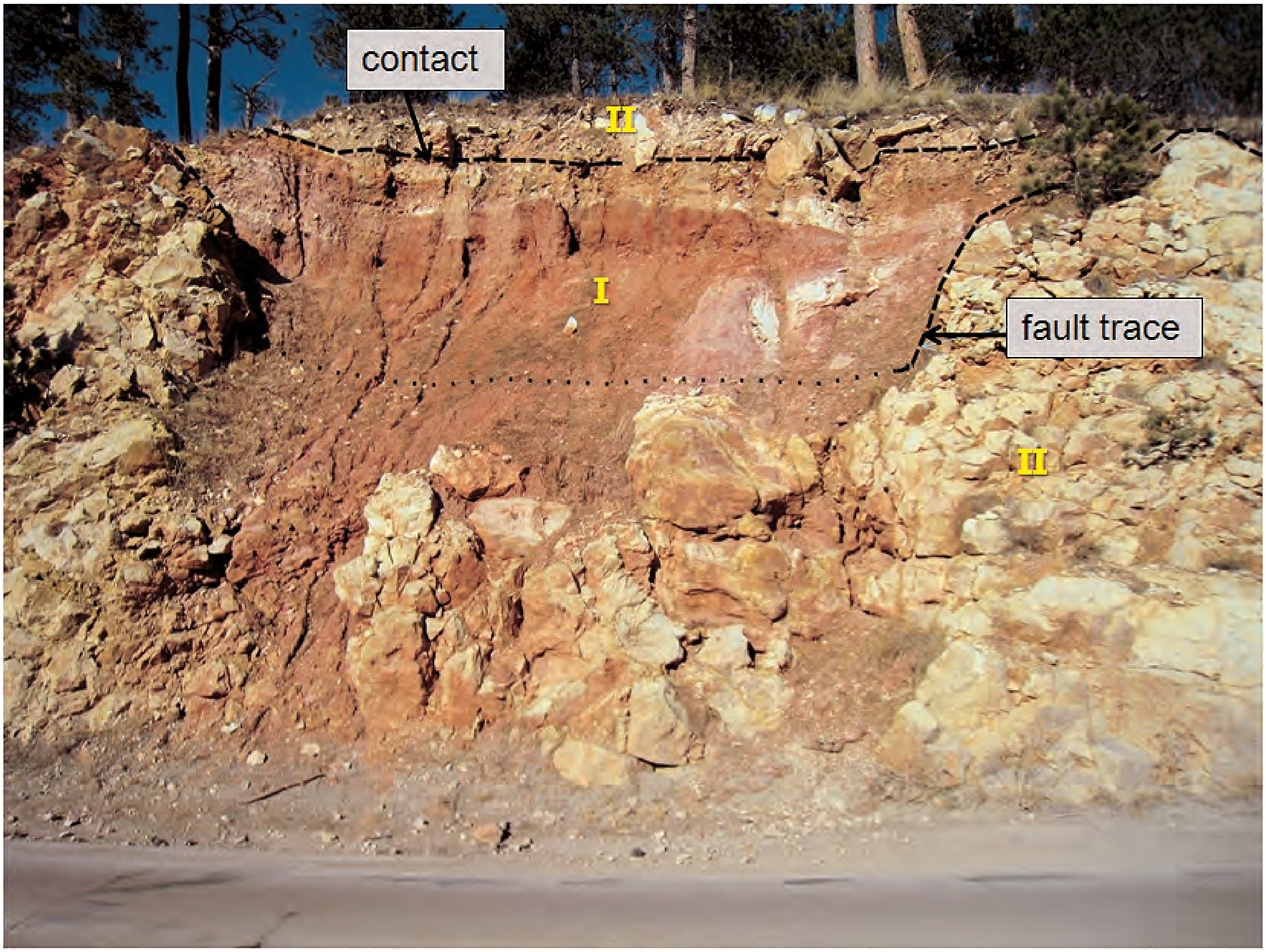

Figure 6. A faulted area that is easily misinterpreted as a paleo-sinkhole

red siltstone of the upthrown block (background) has spilled out of its original location, enhancing the "sinkhole" effect.

Ellipsoidal Clasts

Finally, a new line of evidence, in the form of ellipsoidal clasts of ortho-quartzite (Figure 7), has the potential to clarify the relationship between the timing of geologic events and the origin of Jewel Cave. Until recently, these were believed to be concretions that formed at Pahasapa/Minnelusa contact. However, most show no obvious internal structure. Those that do, usually have features resembling sedimentary layers. Field examination of thousands of clasts has revealed a wide variation in color, shape, and size; but most are brown to reddish-brown, clearly ellipsoidal, and range from 8 inches in diameter and 4 inches thick, to 3 feet in diameter and 18 inches thick

The full extent of the distribution of these clasts is still being determined, but so far they have been found in a band that is 2 to 4 miles wide and extends at least 30 miles north of Jewel Cave, along the western flank of the Black Hills (Figure 8). They are found predominantly in surface drainages, but many can be traced to tops of ridges and divides, up to 7,000 feet elevation – some of the highest elevations in the Black Hills. Yet no source bed has been discovered, whether it be a quartzite rock layer, pieces of which have been rounded to an ellipsoidal shape during fluvial transport; or even a layer of sedimentary rock containing ellipsoidal concretions. However, even though their origin remains unknown, their distribution clearly crosscuts the stratigraphy from the top of the Pahasapa to at least the top of subunit III of the Minnelusa. They seem to have been distributed concurrently with the development of the modern topography, and therefore were deposited at least as recently as the forces that shaped the landscape as it exists today.

Ellipsoidal Clasts Inside Jewel Cave

Unexpectedly, two clasts have been found within Jewel Cave. Both are in close relationship with basal Minnelusa material, and one is sandwiched between Minnelusa material and the cave's ubiquitous calcite spar coating (Figure 9). If the cave fill is indeed a recent "neofill," then the clast was deposited as part of that event, or more recently; and the spar coating was deposited even more recently still. Throughout the known cave, the spar seems to be an integral part of a specific fill sequence – representing a final stage of subaqueous deposition – so the former explanation is preferred.

There currently is no clear explanation of how or when


Figure 8. Currently known distribution of the quartzite clasts

the clast was emplaced, but because the surface distribution of the clasts cross-cuts the overlying strata, the event must have occurred after the uplift of the Black Hills and subsequent erosion of over 5,000 feet of overlying sedimentary rock. Even so, a mystery remains: The clast in Figure 9 is located in an area where the Pahasapa Limestone is overlain by over 200 feet of non-cave-bearing rock, with no likelihood of nearby cave entrances – past or present. Clearly much more work is needed to unravel this newfound mystery.

Conclusion

The observations presented in this paper demonstrate a strong correlation between the passages of Jewel Cave and modern surface features. The evidence suggests that Jewel Cave formed as a result of the most recent processes that shaped the present-day stratigraphy, structure, and topography. This gives pause for re-evaluation of the origin of Black Hills caves and will hopefully encourage new research to resolve the questions that have been raised.

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Figure 9. One of two quartzite clasts found with Jewel Cave – it was discovered in 2010

Powell Mountain Karst Preserve: Strategies for the Permanent Protection of Omega Cave and Related Karst and Surface Resources

Joseph H. Fagan
Karst Hydrologist and Environmental Planner
Joseph Fagan and Associates, 403 Franklin Drive, Blacksburg, Virginia 24060
joseph.fagan.and.associates@gmail.com

Michael J. Ficco
Geologist
8140 Cumberland Gap Road, New Castle, Virginia 24127
mficco@mindspring.com

Wil Orndorff
Karst Protection Coordinator
Virginia Department of Conservation and Recreation Natural Heritage Program
8 Radford Street, Christiansburg, Virginia 24073
wil.orndorff@dcr.virginia.gov

Abstract

The Cave Conservancy of the Virginias (CCV) owns and manages the 170-acre Powell Mountain Karst Preserve (PMKP) in Wise County, Virginia. In 2011, the CCV granted a perpetual conservation easement on the PMKP to the Virginia Outdoors Foundation to ensure its permanent protection. PMKP contains five known caves, including the Blowing Entrance to Omega Cave and the historic saltpetre sites in Parsons Cave and Franklin Pit. Recent exploration extended the surveyed length of Omega Cave to nearly 30 miles. With a depth of more than 1200 feet, Omega Cave is Virginia's longest cave and is the deepest cave in the USA east of the Rocky Mountains. The PMKP is part of a Mississippian scarp-slope karst system exhibiting a complex hydrogeology. Located within the Clinch Valley Bioreserve, the PMKP is part of one of the world's most important remaining biologically diverse intact ecosystems. The CCV's protection strategy for the PMKP places an emphasis on both significant cave and surface habitat and on multidiscipline science including exploration, cave mapping, and karst hydrological investigations using dye-tracing techniques. In 2008, the CCV contracted the Virginia Department of Conservation and Recreation Natural Heritage Program to conduct a biological inventory of vascular plants and plant communities and selected animal groups within the PMKP. Work included bat hibernacula surveys, mist netting, cave invertebrate sampling, general non-cave invertebrate sampling, a botanical survey, and natural community classification. Stewardship efforts include cooperation between cavers, the U.S. Forest Service, and various state agencies.

Management Guidelines for Caves and Karst in Parks Canada's Heritage Areas

Presented by
Greg Horne, Resource Management & Visitor Safety Specialist
Jasper National Park, Box 10, Jasper, Alberta, T0E 1E0, Canada
greg.horne@pc.gc.ca
780-852-6259

Written by
John Waithaka, Conservation Biologist
Parks Canada Ecological Integrity Branch - National Parks Directorate
25 Eddy Street, Gatineau, Quebec K1A 0M5, Canada
john.waithaka@pc.gc.ca
819-997-4937

Abstract

Guidelines have been drafted to apply to cave and karst areas and their associated resources in all Heritage Areas managed by Parks Canada, the agency managing federal protected areas including national parks. The purpose of the guidelines is to ensure effective protection and management of caves and karst areas, including their natural and cultural resources and values.

A balance of use for the purposes of conservation, research, public education, visitor use and other activities related to cave and karst areas are delineated in a manner consistent with Parks Canada policies, legislation and corporate priorities. Basic management requirements for managers of Heritage Areas are outlined. The importance of a resource inventory is stated and potential documentation criteria listed.

A three-tier cave classification for management and access purposes is defined and ranges from restricted to full access for the public. A selection of activities for cave and karst areas is presented that includes: research/collection, recreation, commercial, restoration, and public education.

The importance of staff training and annual reporting related to the areas of caves and karst is acknowledged.

This is the first time a national in scope series of guidelines has been drafted for the Parks Canada Agency. Although limited in detail, the guidelines provide more direction than was ever previously available for resource managers.

Background

Parks Canada's Heritage Areas include 42 National Parks or National Park Reserves, 950 National Historic Sites (167 administered by Parks Canada) and 2 National Marine Conservation Areas in Canada. A 2009 survey revealed 25 National Parks and Reserves contain cave and karst resources.

No national directives or guidelines exist for cave or karst management; however, park-specific guidelines have been developed. A Parks Canada working group representing a selection of the parks with significant cave and karst resources and staff from regional and national offices was formed. Conference call meetings were held and preliminary drafts circulated by e-mail for further input and editing. As of October 2011 these management guidelines are only in draft form. Since they have not been formally approved and released, it is not appropriate to publish in these proceedings the full text of the guidelines. An abridged summary of the guidelines is provided below.

1. Introduction

1.1 Scope

The guidelines apply to all cave and karst areas and their associated resources in all Heritage Areas managed by Parks Canada.

1.2 Purpose

1. Ensure effective protection and management;
2. Ensure other activities are conducted in a manner consistent with Parks Canada policies, legislation and corporate priorities;
3. Provide guidelines for use and access;
4. Encourage and promote the engagement of the scientific and caving communities and the public;
5. Enhance appreciation and understanding of the resources.

1.3 Main References and Authorities

A broad selection of federal acts, regulations, bulletins, guidelines and agreements were consulted, a minimum of twenty.

1.4 Definitions

A short selection of key terms used in the guidelines are defined. Be aware that cave, as defined by the Canada National Park Act and Regulations, means "any subterranean cavern or area, either natural or man-made."

1.5 Background

A brief summary of the significance and importance of cave and karst resources is presented.

2. Basic Cave and Karst Management Requirements

Actions for managers of Heritage areas include:

1. Ensure the maintenance of ecological and commemorate integrity;
2. Facilitate opportunities for users;
3. Carry out basic inventory of caves and karst areas and resources contained within;
4. Ensure restoration, wherever possible;
5. Administer, support, and encourage research and collection activities;
6. Require that specimens legally removed are lodged with a recognized institution for proper curation, storage, and conservation;
7. If required, limit access using appropriate methods;
8. Ensure management actions in karst areas mimic those occurring naturally;
9. If necessary, develop expertise and capacity for cave and karst management.

3. Cave and Karst Inventory

1.1 Caves

The importance of cave inventory and its contents is stressed. Suggested attributes are listed and possible delivery methods presented.

1.2 Karst

It is recommended a complete inventory be completed. The information will be used to ensure appropriate protection and use and incorporate these actions into management programs.

4. Cave Classifications for Management Purposes

For management purposes, caves shall be classified into (i) Restricted Access Caves, (ii) Limited Access Caves or, (iii) Unrestricted Access Caves, based on natural and cultural resource values, vulnerability to impacts, and risks to users.

4.1 Category 1 – Restricted Access Caves

The attributes of these caves include: extremely fragile resources, human remains, high cultural significance, species at risk, extreme hazards. Access will be very restricted.

4.2 Category 2 –Limited Access Caves

The attributes of these caves include: vulnerable resources but can accommodate limited use and or hazards requiring extra precautions.

4.3 Category 3 – Full Access Caves

The attributes of these caves include: resources not considered to be vulnerable to public use or to present a significant risk to public safety. Access may be either guided or self-guided. If use levels warrant, specific guidelines, education materials and monitoring may be developed.

5. Activities in Caves and Karst Areas

5.1 Research and Collection Activities

All research and collection permit applications must be submitted through the Parks Canada Research and Collection Permitting System. Applications will be peer-reviewed by relevant experts. Research permits will be for inventoried caves only unless the inventory is part of the application. Invasive research should be restricted to the minimum activity required to achieve the objectives of the study.

5.2 Recreational Activities

Suitable areas and activities should be identified for a broad spectrum of visitors. Provide these visitors with appropriate information. Match use with fragility of the resource and monitor to improve management effectiveness. Enable user feedback on their experiences.

5.3 Special Activities and Events

Special events, including commercial activities, require a business permit and / or license of occupation. As an assessment to ensure compliance, a directive on recreational activity and special events would be completed. Guided cave tours, speleofests, rescue practices are examples.

5.4 Restoration of Damaged Caves

Foreign materials impacting the ecological and commemorative integrity will be removed. The methods used to do so will comply with natural and cultural resource management policies and guidelines. Restriction of access may be used as part of the restoration process.

5.5 Public Education

User education/orientation is very important for resource conservation. This information includes specifics for targeted groups, awareness of terrain difficulty, low-impact practices, experience requirements, resource vulnerability, and ways for public involvement.

5.6 Public Safety

Information on known hazards should be identified and provided to cave users [presenter's note, at the 2007 National Cave and Karst Management Symposium he proposed Cave Terrain Guidelines as a method to educate users what is present in the cave they are planning on visiting (Horne 2008)]. Access to caves containing unusual hazards should limited to qualified users and extremely hazardous caves closed to the public.

6. Staff Training

Heritage Area managers should match cave/karst terrain with appropriate training for staff to safely conduct planning and management activities. This will involve developing a formal training program for staff and could include requirements for volunteers, contractors and other partners whose assistance may be needed from time to time.

7. Reporting

A summary constituting part of the Heritage Area Annual Report should be prepared summarizing cave and karst area activities and impacts. Topics to document include: visitation, user feedback, key results of research and monitoring efforts, results of restoration and resource management efforts, management challenges, needs and opportunities.

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Update on the Development of the NPS Cave Visitor Impact Vital Signs Monitoring Protocol

Rodney D. Horrocks
Physical Science Specialist,
Wind Cave National Park
605-745-1158
rod_horrocks@nps.gov

Abstract

Cave photomonitoring projects have shown that in low-energy cave environments, gradual change is almost imperceptible to humans; thus long-term monitoring methods have been developed. These changes, which have cumulative impact, are caused by cave visitation. Although monitoring cave visitor impact has been a priority of the cave management community for a long time, these efforts were only developed for single caves or parks. No attempt was made to develop national vital signs until the Mammoth Cave Ecosystem Workshop of 2003. At that workshop, National Park Service cave management specialists identified major threats to cave and karst resources and the vital signs that should be monitored. However, cave visitor impact was not one of the six vital signs identified. The second attempt to develop national protocols was initiated at the NPS Cave Vital Signs Workshop held in Lakewood, Colorado in 2008. This workshop revisited the Mammoth Cave list and identified the vital signs that were common to all caves. Cave visitor impact was added as a vital sign protocol that would be developed and a committee was organized to accomplish that task. This group decided that the protocol would address four parameters of human impact on caves, which include: cave visitation, visitor touching, speleothem breakage, and cave visitor traffic. This presentation will present a status update on the development of this protocol.

Background

It has been demonstrated many times using photomonitoring techniques, that in low-energy cave environments, gradual change is almost imperceptible to humans (Figures 1 and 2). Because of this, long-term monitoring methods have been developed for caves. These changes, which have cumulative impact, are usually caused by cave visitation. Although monitoring cave visitor impact has been a priority of the cave management community within the National Park Service (NPS) for a long time, these efforts were only developed for single caves or groups of parks on a regional level. No attempt was made to develop protocols to monitor national cave vital signs until the Mammoth Cave Ecosystem Modeling Workshop of 2003.

The 2003 workshop was primarily held to start the long-term ecological monitoring program in the Cumberland Piedmont Monitoring Network (CUPN). Mammoth Cave National Park had been chosen as the prototype for cave-and-karst biome monitoring in the network, so that they would be able to provide technical expertise and protocol assistance to the other two parks in the network with major cave resources. At the 2003 workshop, which was held at the Cave Research Foundation's Hamilton Valley facility near Mammoth Cave National Park in Kentucky, NPS cave management specialists from around the country identified 12 major threats or stressors to cave and karst resources, as well as national vital signs that should be monitored at NPS caves. The stressors that were identified included: prescribed fire, logging, land use, invasive exotics, air pollution, water pollution, spills, development, over collecting by researchers, vandalism, and mismanagement. Some of the national vital signs identified at that workshop were: trends of biotic communities, water quality, air quality, energy inputs, mineralogical resources, geological resources, and land use. Interestingly, cave visitor impact was not one of the six vital signs identified.

The CUPN had decided to develop protocols for three major ecosystems: aquatic, caves, and terrestrial (Leibfreid, 2005). For caves, they developed protocols for monitoring woodrats, crickets, cave aquatic biota, beetles, and cave meteorology; primarily based on the needs of Mammoth Cave National Park. These protocols were developed based on the guidelines found in Oakley (2003). However, out of the five protocols, only the cricket and woodrat protocols were actually implemented by the park and no protocols were developed for any of the six national vital signs identified at the 2003 workshop.

A second cave monitoring protocol was recently developed in the Pacific Northwest by the Klamath Inventory and Monitoring Network (KLMN) of the NPS. They contracted with ZARA Environmental LLC to develop a long-term cave monitoring protocol for Lava Beds and Oregon Caves National Monuments. This protocol concentrates on cave climate, ice and water levels, human visitation, coverage of ferns, mosses, and lichens, bat colonies, scat deposition, and invertebrate communities in caves. Pertinent to the Cave Visitor Impact Protocol currently being developed, the KLMN Cave Protocol addresses human visitation, which is one aspect of the Cave Visitor Impact Protocol. The stated purpose for monitoring human visitation, "is to help discern whether visitors are affecting the observed variation of measured parameters and to cue resource managers to respond and limit these negative effects" (Krejca, 2010). ZARA intended that these protocols would be used to collect data consistently and in such a way

Figure 1. Before picture: A carbide sign written on a rock at Buffalo Gap in Wind Cave. NPS photo.

as to provide defendable results for use in scientific research, public interpretation, and management of park resources. Unfortunately, this protocol is also regionally based and does not address the national vital signs monitoring parameters.

Discussion

The second attempt to develop national vital signs monitoring protocols was initiated at the NPS Cave Vital Signs Workshop held in Lakewood, Colorado in November of 2008, under the direction of Denis Davis, then the Superintendent of Timpanogos Cave National Monument. Thirty three people representing three groups, including various National Park Service sites with cave and karst resources, NPS programs that could potentially monitor cave and karst resources, or groups working on contracts to monitor cave and karst resources at NPS sites, gathered for this workshop. This workshop was convened because the 32 Inventory and Monitoring Networks of the National Park Service, for the most part, did not fund protocol development for cave and karst vital sign monitoring, except the two protocols described in the background section above. Unfortunately, those two protocols were not for parameters that were applicable to all caves across the country, but geared towards regional concerns. The Lakewood workshop began by revisiting the vital signs generated at the Mammoth Cave Workshop and compiling a new list of vital signs that were common to all caves. After two days, the group decided that the monitoring priorities applicable to all cave and karst sites were: cave visitor impacts, hydrology, cave meteorology, and cultural/paleontological resources. It was decided that SOPs would be developed for inventory, ecology, and cultural/paleontology while monitoring protocols would be developed for cave visitor impact, hydrology, and cave climatology.

A volunteer working group, headed up by Rod Horrocks from Wind Cave National Park, was formulated to begin work on the cave visitor impact protocol. Rod was joined by Elizabeth Hale from Oregon Caves National Monument and then later by Lee-Gray Boze, from Jewel Cave National Monument and Shane Fryer, from Lava Beds National Monument.

The first thing the group decided was that the Cave Visitor Impact protocol would address four parameters of human impact on caves, which include: cave visitation, visitor touching, speleothem breakage, and cave visitor traffic. Rod volunteered to write the background, objectives, personnel, and operational requirements sections. Lee-Gray took on the cave visitation and visitor touching sections. Shane undertook the speleothem breakage section and Elizabeth tackled the Visitor Traffic section. As of today, most of these authors have produced rough or partial drafts of their sections. The group has established a deadline for completion of a final draft protocol by the spring of 2012.

Summary

Once the Cave Visitor Impact Protocol is completed, the Cave Visitor Impact Protocol working group will work with personnel from the NPS Midwest Regional Inventory & Monitoring group, stationed in Rapid City,

Figure 2. After picture: The same carbide sign written on a rock at Buffalo Gap as it looked in 1997 after many years of caver traffic along the adjacent trail. (compare with the 'before' picture, Figure 1). NPS photo.

South Dakota, to produce a document that can then be peer reviewed by the winter of 2012. It is hoped that the Cave Visitor Impact Protocol will be completed by the spring of 2013.

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Alpine Cave and Karst Management on the Tongass National Forest

Johanna. L. Kovarik
Geologist, U.S. Forest Service
740 Simms Street
Golden, Colorado, 80401
jkovarik@fs.fed.us
303-275-5378

Abstract

The Tongass National Forest is the largest forest in the National Forest System in the United States, encompassing over 6.9 million hectares covering the islands of the Alexander Archipelago and the narrow band of mainland from Dixon Entrance to Icy Bay. The Tongass contains 85% of the total karst in southeast Alaska, approximately 220,000 hectares primarily on Chichagof, Prince of Wales, and surrounding smaller islands. Cave and karst resource management focus is primarily on areas where timber harvest is permitted: however in Tongass geologic special areas alpine caves are managed for their unique resources including paleontology, archaeology, and biology. The Tongass conducted work in alpine caves over the past two years including installing monitoring equipment, inventorying new caves, and surveying leads in Snowhole and Blowing in the Wind on El Capitan Peak.

Introduction

The Tongass National Forest is the largest forest in the National Forest System in the United States, encompassing over 6.9 million hectares covering the islands of the Alexander Archipelago and the narrow band of mainland from Dixon Entrance to Icy Bay (Figure 1).

The Tongass contains 85% of the total karst in southeast Alaska; approximately 400,000 hectares primarily on Chichagof, Prince of Wales, and surrounding smaller islands (Figure 2).

The largest area of karst development exists on Prince of Wales and surrounding islands, which contain approximately 1,813 km^2 of karst (Baichtal 2006). These karst areas are concentrated on the north end of the island and surrounding smaller islands, where over 600 caves have been mapped. Karst formed to some extent on Prince of Wales prior to the Wisconsin glacial advance 21,000 to 14,000 years ago. This period of glaciation caused scouring, passage collapse, and sediment fill in karst systems, as well as leaving thick glacial till deposits and razing epikarst development at lower elevations. The intense development of karst on the Tongass National Forest is controlled

Figure 1. Southeast Alaska and the Tongass National Forest (US Forest Service).

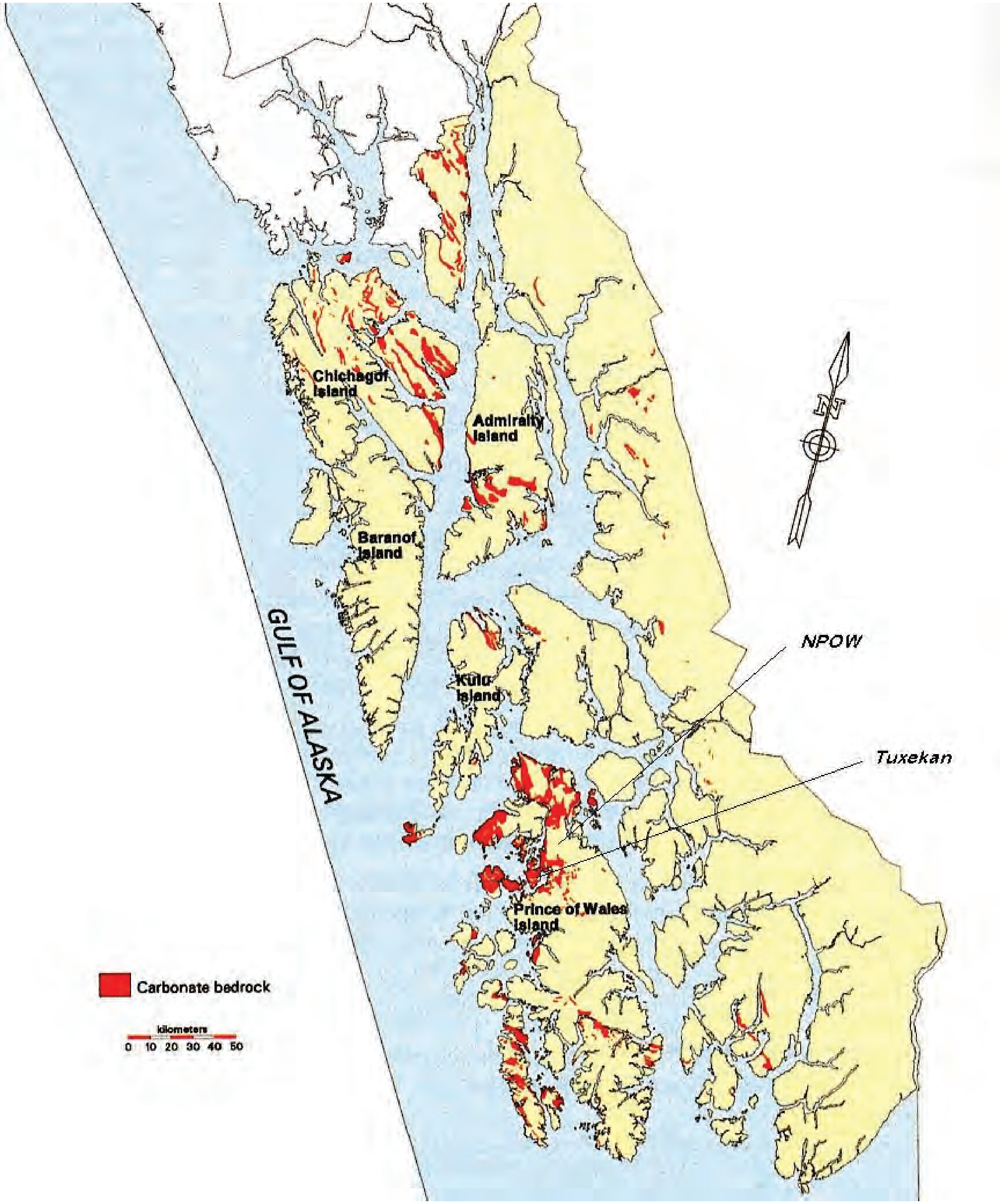

Figure 2. Carbonate rock on the Tongass National Forest (US Forest Service).

by several factors including the high percentage of calcium carbonate ($CaCO_3$) in the limestone of southeast Alaska – averaged at 97.65 percent (Maas *et al*. 1992). In addition, faults and fractures resulting from the northward movements of the Alexander Terrane are dominated by northwesterly trending strike-slip faults and second order intersecting north-trending strike-slip faults, which define karst conduit formation (Gehrels and Berg 1992, Aley *et al*. 1993, Baichtal and Swanston 1996).

On the Tongass National Forest, the protection of cave and karst resources came about shortly after the Federal Cave Resource Protection Act of 1988. The Tongass Cave Project (TCP) began inventorying and exploring caves in southeast Alaska in the early 1980s, and basic karst resource inventories began in the late 1980s and early 1990s. The initiation of karst resource protection on the Tongass together with the mapping projects led by the TCP spurred interest in karst and cave resources in southeast Alaska. Initial work began on inventorying the biological resources in Tongass caves on Prince of Wales and surrounding islands in the early 1990s. Researchers found that mammal species and birds used caves as critical roosting and hibernating habitat, including five species of bats (Baichtal and Swanston 1996). Invertebrate collections from over 300 caves and resurgence sites yielded at least five troglobitic and forty troglophilic invertebrate species; three of those newly discovered (Carlson 1994 and 1996). The caves were found to be rich in paleontological and cultural resources, including the finding of the oldest bones in North America in On Your Knees Cave (Carlson 1993, Dixon *et al*. 1997). As a result, the Forest Service included the Karst and Cave Resource Significance Assessment of 1993 as part of the Tongass Land Management Plan (TLMP) revision process. During this initial assessment of southeast Alaska's cave and karst resources in 1995, alpine karst in southeast Alaska was defined as karst development 700 meters and higher in the southern portion of southeast Alaska, and 450 meters and higher on the northern portion of southeast Alaska. This was mainly due to differences based on latitude, including climate.

One of the main foci of land management on the Tongass is timber harvest. Due to this, geologists on the Tongass focus most karst resource work, such as inventory and monitoring, in timber land use designations where such management is allowable. However, over the past 30 years, cave exploration has occurred within alpine karst areas on the Tongass, and resources researchers and forest service personnel alike have spent time mapping caves and evaluating biological, paleontological, and archaeological resources in these areas due to their significant resources. The uniqueness of these karst areas and the value of the resources found within them became well known during the late 1990s and early 2000s. In alpine karst on Prince of Wales Island, El Capitan Pit, the deepest limestone pit in the United States, was mapped at 182.4 meters, and research by Heaton (1996) characterized vertebrate remains no longer found on the surface in these areas, such as brown bear and caribou.

In the 21st Century, the Tongass again began to revise the forest management plan, and resource managers proposed changes to the karst management strategy. In 2002, a panel was contracted by the Forest Service to assess the implementation of the karst standards and guidelines established in the 1997 TLMP and to analyze proposed changes. The Karst Review Panel found that generally the implementation of Karst Standards and Guidelines had ensured a high level of protection for karst resources; however they recommended a higher level of training for karst specialists and identified some revisions to the proposed changes (Griffiths *et al*. 2002). Finally, in 2008 the Amendment to the 1997 Tongass Land Management Plan was published, including some changes recommended by the karst review panel for cave and karst resource inventory and monitoring. An additional major inclusion in the 2008 amendment included establishment of several Geologic Special Areas in major alpine karst areas around southeast Alaska.

Southern Tongass National Forest

A great quantity of the exploration and resource work in alpine areas on the Tongass National Forest has occurred on Prince of Wales and surrounding islands in southern southeast Alaska. During the 1990s and 2000s several expeditions were based off of northern Prince of Wales Island and surrounding islands such as Dall, investigating El Capitan Peak, as well as Perue, Virginia, and Calder peaks.

As mentioned above, the deepest limestone pit in the United States was mapped on El Capitan Peak, as well as several other caves including Blowing in the Wind, Snowhole, and Bumper caves. Leads remained after the initial mapping expeditions, and Blowing in the Wind and Snowhole caves were targeted by an expedition in 2010. Two separate main leads were pushed in Blowing in the Wind, including a bolt climb into passage, which was again left as a lead; however, descending most likely into known cave. The next was a pit, which was connected with known cave. An additional 188 meters was added to the survey, with no significant leads remaining (Figure 3).

The leads left in Snowhole were more promising, including two going pitches on the north and south end of the cave. These two pitches were pushed through, and over 200 meters were added to the cave. One particularly nice lead remains, a pit approximately 23 meters deep with the sound of water at the bottom (Figure 4).

In addition to exploration, Kevin Allred, a caver with the TCP, is currently monitoring dissolution rates utilizing bolts placed in the bedrock. The Tongass National Forest has included a cave in the alpine karst area on El Capitan peak in a cave climate-monitoring project, with RH and temperature data loggers placed throughout the cave.

On Calder Mountain, an expedition in 2008 went searching for two pits previously located by TCP cavers Steve Lewis and Kevin Allred (Figure 5).

In 1992 Lewis and Allred were dropped off on the top of Calder Mountain by a helicopter with only 45 minutes for exploration. The two cavers located two pits: Chopper Bopper near the peak of the mountain. Before they had to jump back into the helicopter as inclement weather threatened to strand them there, they dropped Chopper Bopper to a depth of approximately 30 meters and an additional pit estimated at 30 meters deep. The expedition in 2008 was limited to four days on the ridge that led to Calder Mountain. While they located and mapped four new caves, the cold summer resulted in snow filling many of the entrances, and Chopper Bopper and the unnamed pit were not relocated.

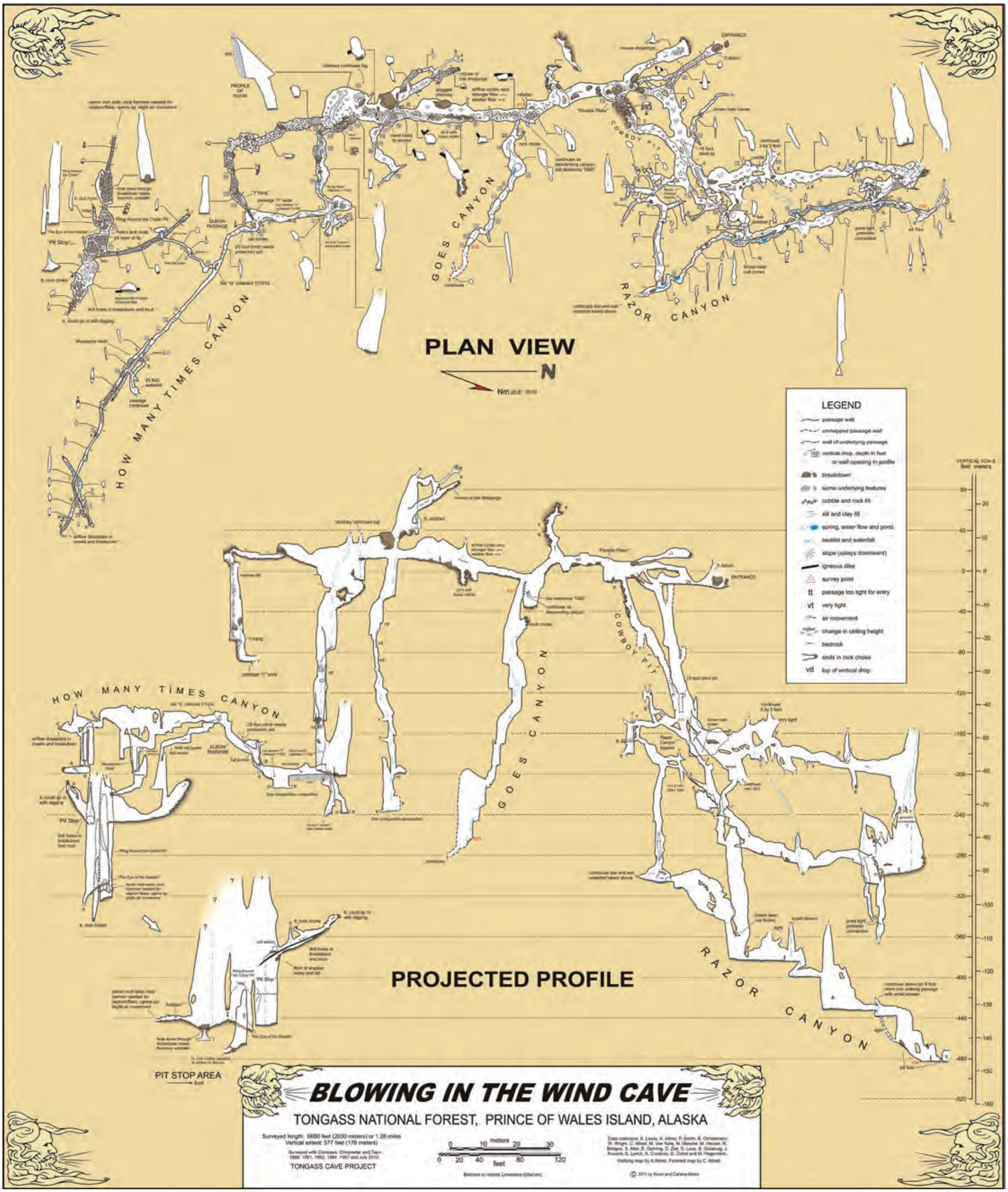

Figure 3. The 2010 map of Blowing in the Wind (C. Allred).

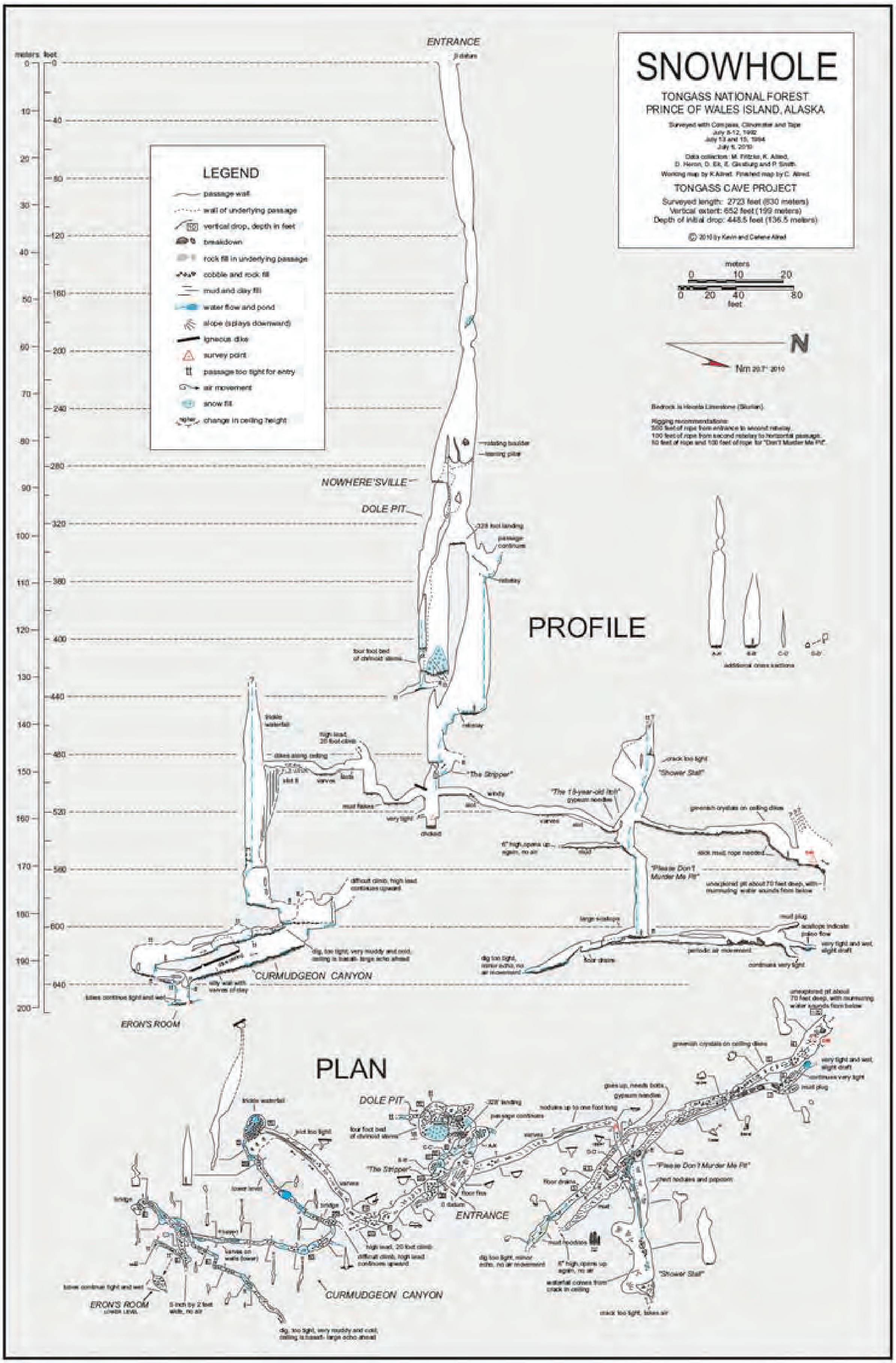

Figure 4. The 2010 map of Snowhole (C. Allred).

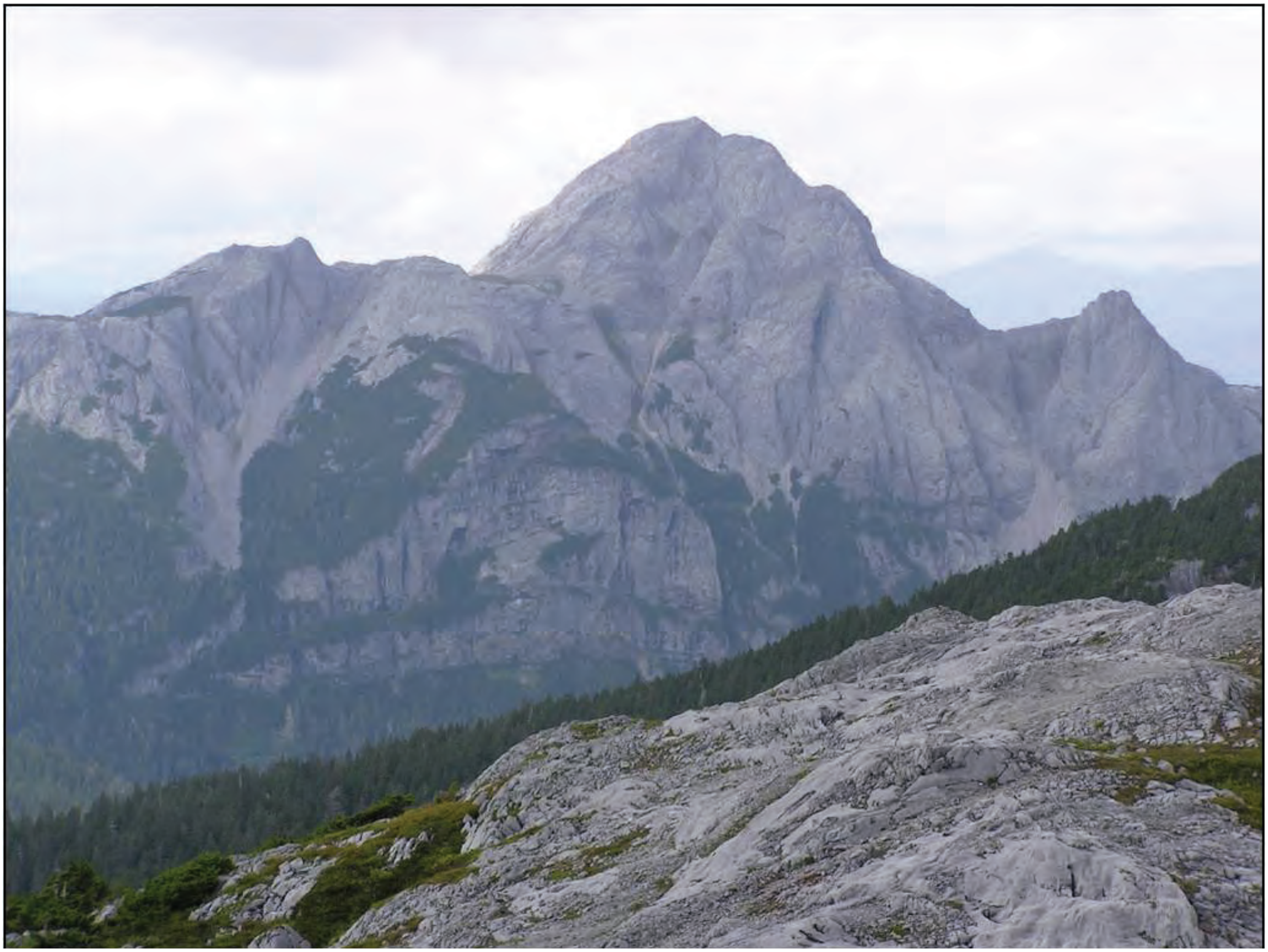

Figure 5. Caption: Calder Mountain rises over 1000 meters high on the northern end of Prince of Wales Island (J. Kovarik).

Dall Island, south and west of Prince of Wales, also contains areas of alpine karst with dramatic epikarst development. Many photographs displaying the karst of southeast Alaska are taken from this location (Figure 6).

Alpine karst exists in the north and central parts of Dall Island. In the north, Devil Karst Area contains alpine tundra vegetation growing on pockets of glacial till in the epikarst and on weathered dike surfaces. In the central part of the island, water from a glacier's margin flowed into fractures 25 meters in depth – forming in massive highly fractured Ordovician to Silurian aged metalimestone. The TCP and Forest Service have conducted several cave exploration trips on Dall Island, including the mapping of Mossy Abyss pit at 152 meters deep in the alpine.

Northern Tongass National Forest

On eastern Chichigof Island, barren karren characterizes Sonyakay ridge at 744 meters of elevation. A reconaissance trip in 2005 visited Sonyakay ridge but did not locate any caves (Figure 7).

Unnamed Mississippian and Silurian to Lower Devonian carbonate ridgelines running parallel and south of Sonyakay ridge have never been explored. On the western side of the island a limestone peak rises to 1150 meters, and springs emanating from this ridge provide calcium-rich waters for calcareous fens, which show enhanced diversities of flora and fauna. Informal investigations on the Vortex, a carbonate peak on the western side of Chicagof did not locate any large caves. These karst ridges were overridden by glacial ice during the Wisconsin glacial period. They were deglaciated approximately 12,000 to 13,000 years ago. Areas of marble underlie Admiralty Island, including marble cliffs along the eastern shore of the island along Chatham Strait. Admiralty Island is a wilderness area, which makes access difficult. Little to no exploration of the carbonate on this island has occurred.

Conclusion

Several groups have done a great amount of work documenting and mapping karst features and caves in the alpine areas on the Tongass National Forest. These groups have discovered great number of significant caves and valuable cave resources including paleontological and archaeological items which have contributed greatly to the understanding of glacial history and subsequently to human and geologic

Figure 6. Intense epikarst development on Dall Island (J. Baichtal).

history. However, due to the vast amount of carbonate rock and difficulty in access to remote alpine areas, several areas remain for future exploration.

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Figure 7. Alpine karst ridges on northeastern Chichigof Island (J. Baichtal).

Nutty Putty Cave – Manual Cave Management Nightmare or Automated Website Tranquility

Michael Leavitt

When taking on the task of managing a highly visited and gated wild cave owned by a Utah State agency, you have monumental challenges and hurdles to overcome. These obstacles include the creation of:

1) Memorandum of Understanding.
2) Waivers and releases.
3) Access and caving rules.
4) Rules for qualifying Trip Leaders.
5) Method to distribute locked gated access for up to 6 caving groups a day, 7 days a week.
6) Method of acquiring trip reports for each caving group.
7) Creation of regular Cave Management Team inspection procedures and reporting.

In short, these are the perfect ingredients for either a manually managed nightmare, or a well-tuned automated website. This presentation deals with how and why I created and implemented the latter. We will visit the www.NuttyPuttyCave.com and discuss the features and information needed for the complete website caving reservation experience.

Crumps Cave Preserve: A Unique Case of Acquisition and Management of a Cave System for Karst Research

Benjamin V. Miller
Western Kentucky University, Hoffman Environmental Research Institute
1906 College Heights Blvd.
Bowling Green, KY 42171

Abstract

Crumps Cave is a 2-kilometer-long cave located on the Pennyroyal Sinkhole Plain of south-central Kentucky. The cave, briefly developed as a private show cave, is known for archaeological and speleological significance. A process was initiated in 2007-08 to acquire the cave for research and education/outreach by the Hoffman Environmental Research Institute at Western Kentucky University (WKU). A grant was awarded by the Kentucky Land Heritage Conservation Fund to WKU and the two acres encompassing the entrance sinkhole was acquired. Following this acquisition several inventories were conducted examining the archaeological and biospeleological resources, in addition to surface flora and fauna. Management decisions for the cave and preserve are evaluated and carried out by a three-member management team comprised of WKU faculty and staff. Today the cave is a major site for hydrogeologic research, where impacts from surrounding agricultural operations are studied at several epikarstic waterfalls interspersed throughout the cave. Monitoring of the environment in and around the cave is gathered from a series of five data loggers measuring 22 parameters. The cave is also being utilized as an underground classroom which is visited by WKU and other university classes in the disciplines of geology/geography, archaeology, and biology. Recently the remains of a lighting system and 200 meters of boardwalk were removed in a cooperative effort between several NSS grottos and WKU. Crumps Cave Preserve will continue to be a site available for use in a variety of fields in cave and karst research, as well as a significant facility used for education and outreach.

Introduction and Setting

In cave and karst management, features such as sinkholes, springs, and caves are frequently acquired for aesthetic and recreational value or to preserve resources of known significance. The subsequent management of these features is often then dictated by the reason for the acquisition and by mandates from governing agencies or management boards. In the case of Crumps Cave, a significant cave has been acquired and is currently managed specifically for use as a research facility as well as educational purposes. Crumps Cave Preserve is a 2.5 acre property owned and managed by the Hoffman Environmental Research Institute at Western Kentucky University (WKU). It provides an excellent example of a significant cave managed specifically for use as a research facility, as well as for educational purposes.

Crumps Cave is a 2-kilometer-long cave which is located in the central portion of the Pennyroyal Plateau in south-central Kentucky. Crumps is known for the significance of the archaeological, biological, and hydrological resources found within the cave and the surrounding sinkhole. The cave was explored and studied in the past due to the cave's voluminous passages which are the largest continuous passages on the sinkhole plain (Figure 1), and the cave's close proximity to a major groundwater divide between Graham Springs and Turnhole Spring (Hess *et al*., 1989). Archaeological investigations in Crumps Cave examined the rich deposits of material in the cave's entrance and 2,000 year-old mud glyphs located 1,200 meters into the cave (Davis and Haskin, 1993; Faulkner, 1997). Biologically the cave has a number of documented invertebrates and is listed as a site for Gray bats, *Myotis griescens*, providing habitat for an apparent summer season bachelor colony. The cave is formed within the Mississippian St. Louis Limestone just below the Lost River Chert, which acts as a leaky confining layer providing flow to the many in-cave waterfalls. The land use surrounding and above Crumps Cave is dominated by agricultural practices, with both row cropping of corn and soybeans adjacent to plots used for cattle production. Since the cave is located in the headwaters of the large groundwater recharge basin for Graham Springs, the impacts from the overlying and surrounding agricultural can be examined at epikarstic waterfalls in-cave which drain a smaller estimated area of perhaps 0.01 km^2 in size. By examining land use patterns, research findings can assist to better quantify and correlate the impacts from various types of agriculture to water quality in the overall Graham Springs basin, an area greater than 360 km^2.

History of WKU and Crumps Cave

Crumps Cave and Western Kentucky University have had a long history together, partly due to the close proximity of the cave to WKU but also because of cave exploring and research opportunities utilizing the cave. Prior to the 1980's, access to the cave was largely uncontrolled; however, during this time the first map was produced by surveyors from WKU,

Figure 1. Main trunk passage of Crumps Cave. Photo by Jason Polk

directed by James Quinlan, showing the cave to be 1,737 meters in length. In the early 1980's, Ken Carstens visited the cave and noted large amounts of archaeological material in the entrance area of the cave but returned a few months later to find the cave entrance heavily looted. In 1985, Bill Marohnic purchased the property surrounding and including the cave in order to operate a bed and breakfast. Mr. Marohnic, who was an excellent steward of the property containing the cave and was very caver friendly, owned the cave up until the acquisition by WKU. Organized cavers were allowed into the cave during this period of time, producing a second map of the cave and stretching the length to 2,053 meters. In 1988, during this survey effort, a team of WKU students discovered pre-historic mud glyphs deep in cave which were subsequently dated to 2,000 years before present. The cave was gated in 1993 by the American Cave Conservation Association and the Kentucky Heritage Council, following the discovery of the mud glyphs and in an effort to preserve Gray bat populations. Research, in collaboration with the United States Department of Agriculture - Agricultural Research Service (USDA-ARS), was initiated in 2004 to study the variations in water chemistry and storage in the epikarst aquifer (Groves *et al*., 2005). During this period of time, since the research was funded through grants a courtesy "rental" fee was paid to Mr. Mahronic for access and use of the cave for research. In 2005, the process was initiated to acquire Crumps Cave by WKU for research and educational purposes.

Acquisition Reasons and Process

The Kentucky Heritage Land Conservation Fund (KHLCF) is a state funding organization that provides funding for preserving and conserving natural areas that possess unique natural features (*Energy and Environment Cabinet, Kentucky Heritage Land Conservation Fund,* 2011). The KHLCF receives its revenue from the purchase of "Kentucky Nature's" Finest vanity license plates and from environmental fines paid to the state. Generally, sites purchased by the KHLCF enhance biodiversity or protect crucial threatened and endangered species habitat. In the case of Crumps Cave, the Gray bat populations had a significant impact on the awarding of the grant. Grant applications are reviewed, discussed, and potentially awarded by a 12 member board composed of State land managers and appointed citizens. Over the 17 years of the KHLCF's existence the board has awarded funding that has led to the purchase of more than 130 properties, including at least seven sites which are focused on preserving cave and karst features.

In 2004, a grant was submitted to the KHLCF by Hoffman Environmental Research Institute Director Chris Groves, Associate Director Pat Kambesis and WKU Biology professor Albert Meier to acquire the Daleo Entrance to the Roppel Cave portion of Mammoth Cave. The effort was initiated after the university was approached by the landowner about such a purchase for conservation purposes. The idea was to use the cave as a major research site as well as protect the only uncontrolled entrance known at that time to the longest cave in the world. However, although a grant of about $330,000 was subsequently awarded to the WKU team, ultimately they and the property owner were unable to successfully negotiate a purchase price, causing the property to remain unpurchased and the funds returned to the KHLCF. This highlights a sometimes frustrating "political" aspect of cave and land management protection. The original funding proposal was based on an estimate of $1,200 per acre, similar to comparable farm properties in the local counties. After consultation with appraisers, the entrance - which is a wet crawlway - was deemed not to add commercial or development value to the property. The subsequent official appraisal averaged $1,800 per acre which, although rather high, was approved by the KHLCF. Unfortunately, the landowner refused to sell below $4,000 per acre and the deal fell through

In 2005, after being approached by Mr. Marohnic about the possibility of buying the cave, the same WKU team made a new KHLCF application to purchase the Crumps Cave property. A grant was awarded and in November 2008 WKU took possession of the 2.5 acres of property, which includes the only entrance to the cave located in the base of a large sinkhole. Today, management decisions at the preserve are evaluated and decided by a three-person management team composed of the grant authors, with additional input from other project participants including WKU faculty and staff, other biologists, and George Crothers, the Kentucky State Archaeologist and Director of the Office of State Archaeology.

Inventories Conducted

As part of the acquisition process the KHLCF requires grant awardees to complete a number of inventories that evaluate and catalogue and quantify the existing resources found within the preserve. In the case of the Crumps Cave Preserve, these inventories included a surface floral survey, surface faunal survey, sub-surface faunal survey, migratory bird survey, and archaeological inventory. The awarded grant includes funding to pay for experts in each field to properly conduct each survey. The results of each survey or inventory are then submitted to the KHLCF board with the annual reports on the preserve. Two of the inventories that are of specific importance to cave and karst management are the biological inventory of the subsurface environment and the archaeological inventory.

The biological inventory was conducted during October 2009 by Julian Lewis and Associates, who had conducted previous bio-inventories in the cave in 2005 during a Kentucky cave shrimp study. The recent inventory utilized 15 pitfall traps in 5 different transects in the cave and Berlese funnels for sampling of terrestrial fauna. For aquatic sampling at the epikarstic waterfalls, the survey used buckets placed under the water flow and then poured through plankton nets after several days. Water samples were also placed in petri dishes and examined under microscope following settling. A total of 41 taxa were documented during the survey, including one previously undescribed troglobitic springtail and 14 other obligate subterranean species. The inventory did note that a general lack of aquatic fauna seemed to pervade the cave during this sampling and hypothesized that this may have been caused by the tourist boardwalk, which extended through the first 200 meters of the cave. This lumber was CCA treated lumber which indicates that the lumber was treated at various times with Copper, Chromium, and Arsenate to prevent rot and insect damage. All of these treatments can be harmful to biota and may be the reason for the general lack of aquatic fauna during the bio-inventory. The cave bio-inventory provided a snapshot of what fauna existed in the cave at the time of acquisition and serves to help guide future cave restoration.

Because of the well-known archaeological history of the cave, the Hoffman Institute had outlined in the grant to conduct an archaeological inventory of the cave upon acquisition. Dr. George Crothers, the Kentucky State Archaeologist, completed the inventory in August and October of 2009 with the help of a University of Kentucky graduate assistant and the author. The cave was known to have fairly extensive "pothole" digging damage in the entrance area of the cave, but it was somewhat unknown what might remain in the portion of the cave inside the gate. It was decided that no digging would take place during the survey and that only surficial material would be inventoried in the cave. The cave was surveyed in 10-meter intervals with all artifacts being flagged and then surveyed using a total station after an area had been thoroughly examined. Since there was such a large amount of deer bone material and chert flakes, it was decided part way through the survey to not document each incident of these materials. Over the period of five days, a total of 369 items were documented in the first 110 meters of cave passage. Items such as intact projectile points or stone tools, which could be used to date the occupation of the cave were surveyed, sketched, and then collected by Dr. Crothers (Figure 2). A total of 31 items were collected from the cave ranging in age from 9,000 years ago to near present day historic items. A transect was also done across the sinkhole to examine what material might be underneath the sediments on the sides and in the base of the sinkhole. Small 2.5 cm cores were drilled using a hand auger and then broken apart by hand to determine what materials were present. In the base of the sinkhole, it was found that 1.0 meter of undisturbed sediments was lain over a 2.25 meter-thick layer of occupational material consisting of burnt nut hulls, wood charcoal, and chert flake fragments. This indicates that the area around and in Crumps Cave has been utilized for quite an extensive period of time. While this inventory has documented the surficial artifacts in the first 110 meters of cave, WKU staff and students have frequently noticed new material that washes out of sediment banks along the passage walls following storm events. Any artifacts found are left *in situ*, unless of exceptional quality, in which case they are then reported to Dr. Crothers for guidance.

Ongoing Research

Since 2004, Crumps Cave has been a major research site; however, since it's acquisition by WKU, the amount of instrumentation placed in and around the cave has increased significantly. The majority of the funding for research thus far at Crumps Cave has been from the USDA-ARS and the research is primarily focused on agricultural impacts on the water quality in and above the cave. Current research is studying

Figure 2. Dr. George Crothers documenting and collecting archaeological material during archaeological survey in October, 2009. Photo by Ben Miller

storage characteristics of the epikarstic aquifer, examining the transport and residence time of both atrazine and fecal bacteria, nutrients, and characterizing epikarstic mixing using isotopic values of δ18O and δ2H from rain and cave water. Crumps Cave is also being used as a research site for a collaborative project with the UNESCO International Research Center on Karst, working to understand and quantify the flux of carbon removed from the atmosphere by karst processes.

Crumps Cave has also proved to be an ideal site for establishing a state-of-the-art monitoring network studying the epikarstic aquifer. The monitoring currently records data on 22 parameters every 10 minutes, which provides a robust data set of 22,100 data points each week, with over 1,000 data points per parameter. An in-cave monitoring station was set up at a perennially flowing epikarstic waterfall where all water falling through the dome is captured and analyzed for various chemical and physical parameters (Figure 3). Monitored parameters include pH, specific conductance, water temperature, discharge at one in-cave waterfall, cave temperature and relative humidity, and a full weather station for monitoring surface weather characteristics. Redundancy of specific parameters has also be instituted in order to have all necessary data in case of data logger or battery failure, and also allows for the calculation of standard deviations ensuring that the quality of the data meets established criteria. By establishing such a monitoring network, it is hoped that the collected data will lead to an understanding of the ongoing surface and sub-surface processes occurring at Crumps Cave Preserve.

Educational Work and Outreach

One of the main goals of the Crumps Cave Preserve is to provide educational opportunities to local schools, universities, and groups from other communities or states. In its capacity as an educational resource, the Preserve has been highly successful. The cave is utilized nearly every semester by classes from WKU in the fields of geography, geology, and anthropology. Classes from University of Kentucky, Texas A & M, Western Ontario University, Miami University of Ohio, and Mississippi State University also visit the cave on a near annual basis. Along with educational institutions, a Farm Day was held approximately six months after WKU acquired the cave in order to acquaint local landowners and neighbors with the activities planned and ongoing at the Preserve. Many field trips for conferences, which tour Mammoth Cave and the sinkhole plain, also now include a visit to the Preserve (Figure 4). Because of this visitation, many renowned karst experts from a variety of different nations have been able to visit the preserve in the first few years of its existence. Due to worries about visiting groups transmitting White Nose Syndrome, each group is now educated first about the disease and asked not to wear items that have been in other caves. Lighting, in the form of headlamps and lanterns, are provided to all visitors and researchers utilize gear dedicated only for use in Crumps Cave.

Cave Restoration

Since biological inventories indicated a marked decrease in the aquatic fauna than had been expected, and had identified the potential threat to biology that the CCA treated lumber boardwalk might pose, it was decided early on to remove the boardwalk from the cave. Other alterations to the cave for the purpose of commercializing the cave, such as lighting, wiring, and piping were also removed at that time. The archaeological survey was also completed prior to any removal of items from the cave, in order to prevent the accidental removal or destruction of any historic items.

The initial deconstruction of the walkway system was completed by 12 members of the Greater Cincinnati Area Grotto of the National Speleological Society (NSS) and the American Cave Conservation Association in March, 2010. This work dismantled and removed the majority of the treated lumber walkway from its location throughout nearly 200 meters of cave passage. However, the lumber was neatly stacked just inside the cave gate and was not removed from the cave into the surrounding sinkhole. One month later, south-central Kentucky experienced severe floods and Crumps

Figure 3. In-cave monitoring station at epikarstic waterfall, showing setup designed to capture and measure discharge. Probes for pH, specific conductivity, and temperature are located in bucket below the large white discharge barrel. Photo by Jason Polk

Cave, normally a dry passage, was filled to the ceiling with flood waters, which had backed up through drains in the floors of domes. This floodwater redistributed the lumber, creating a huge mess and requiring some maintenance to even enter the cave. Over the next few months, graduate assistants and employees of Western Kentucky University worked on moving as much lumber as possible through the gate in order to be removed later.

In February 2011, the Green River Grotto of the NSS, along with other local cavers, met to remove as much of the lumber, wiring and lighting from the cave; moving the material to the base of the sinkhole. Eight cavers succeeded in removing the majority of the lumber and wiring from the cave and dismantling the final segments of the boardwalk. A final trip in May 2011 by the Green River Grotto finally fully removed all of the lumber, wiring, and other trash from the preserve. The material removed from the cave was of sufficient amount to completely fill a 23 m^3 dumpster. While some smaller trash dumps exist along the sides of the sinkhole, the preserve is a much more pristine place to visit now. This huge amount of work would not have been possible without the help of dedicated volunteers of grottos from as many as four states.

Following the removal of the walkway, a new trail was established in Crumps Cave in order to minimize impacts from visitors. This new trail is marked with twin strands of yellow canal line, which is plastic and can handle multiple flood events without degradation. The flood of May 2010 deposited approximately 1.0 meter of sediment over the entire floor of the cave, giving the cave the appearance of being "virgin" floor. This new trail preserves the surrounding, newly pristine cave floor sediments while allowing classes and researchers to still visit the cave system with minimal impact.

Conclusions and Future Work

In November 2008, WKU and the Hoffman Environmental Research Institute took possession of Crumps Cave in Smiths Grove, Kentucky. The primary motivations for the acquisition were to use the cave as a research site for studying epikarstic processes and as an educational resource, as well as to protect endangered Gray bat populations and archaeological resources in the cave. Funding for the acquisition was provided by a grant awarded by the Kentucky Heritage Land Conservation Fund. As a result of this acquisition, several inventories and surveys were conducted to provide information on existing resources and give guidance for management decisions. Additional work will continue to monitor for bat species and hopefully a restoration of aquatic fauna. Research is ongoing in a variety of different areas, studying agricultural impacts to and characteristics of the epikarstic aquifer. An extensive monitoring network is established which provides measurements of 22 parameters on 10 minute intervals, measuring water chemistry, surface weather, and cave microclimate. Many educational groups, both from WKU as well as other universities and local neighbors, have visited the cave as part of field trips. Cave restoration, conducted by grottos of the NSS and in collaboration with the American Cave Conservation Association, has included the removal of the treated boardwalk from the cave and remaining infrastructure from the commercial tour operations. The Crumps Cave Preserve provides example of a case wherein research and educational interests guided the acquisition of the cave, and it will continue to provide a resource for these interests for generations to come.

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Figure 4. Dr. Chris Groves speaking to large field trip group during Karst 2011 conference visit to the cave. Photo by Jason Polk

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Cave and Karst Resources Evaluation For Long-term Protection and Conservation

Dale L. Pate
National Cave and Karst Program Coordinator
National Park Service

3225 National Parks Highway
Carlsbad, New Mexico 88220
dale_pate@nps.gov
575-785-3107

Abstract

Land managers face numerous pressures and issues related to the properties they manage. These pressures and issues can be internal such as aging infrastructure or can come from external sources such as urban sprawl, buried and leaking gas tanks, and a variety of other man-made problems. To adequately protect and conserve properties, land managers need to know their resources. For properties with caves and karst features, the relationship between the surface and subsurface can be complex and confusing at times. This is particularly true in karst areas. Numerous properties only contain portions of karst systems. Without a clear understanding of how surface-to-subsurface interactions take place, managed karst systems may be threatened by contamination or other issues. Cave and karst evaluations for managed properties are necessary to fully understand those resources and to understand the potential for impacts from internal or external factors. Knowing the potential for impacts, both internally and externally, can give the manager the ability to proactively stop or mitigate serious problems before they manifest themselves.

Know Your Resources

Understanding cave and karst resources begins with the determination of the location and extent of those resources. Caves can be very short and simple, but in many areas caves are long and complex. This can apply to caves found in many types of terrains, but especially those found in karst terrains. Karst is a type of land-form that usually includes sinking streams, springs, sinkholes, caves, and other similar surface and subsurface features. Karst systems are such that each karst spring has its own drainage area from which it discharges water received from rainfall that fell on that surface area. It is critical to know the full extent of the drainage area for a karst spring.

Many times, karst bedrock will be intermixed with other geologic formations, making it difficult to know if these resources are within a managing unit and what the extent of these resources may be. Some things to look for are surface expressions such as cave entrances, springs, sinkholes, and sinking streams. These are all indicative of cave and/or karst resources. The interactions between the surface and the subsurface can be very complex. It is of utmost importance for managers to understand these complexities and to make sound decisions based on this knowledge.

Documentation and research play important roles in the understanding of cave and karst resources. In many cases, caves are fragile and every trip can impact these areas. In order to minimize impacts, survey and inventory teams should collect as much high-quality data as possible. For caves, it is important to know the size and extent of passages and where they are located in relation to other passages, caves, and surface features. It is also important to know what caves contain. Standards should be developed for surveys and inventories done within caves. There are at least two types of inventories that will provide good information. These are basic inventories and specialized inventories. Basic inventories for caves should include types of speleothems, minerals if known, water present or absent, general biology, general paleontology, general archeology, and other items that may be useful to know for specific caves. Specialized inventories would include specific items such as types of animals present to species, exact minerals, species of animals represented by bones and other materials, specific archeological material, and other items. Most, if not all, of these more specific inventories will require collections and a specialist to complete identifications. These specialized inventories many times would fall into the category of research.

For karst areas, documentation and research of numerous factors can help in the understanding of these complex resources. This would include dye-tracing sinking streams and sinkholes to determine specific flow-paths to specific springs, determining entire recharge areas for specific springs, measuring quantity of water-flow over long periods of time, analyzing water samples for contaminants and other constituents, collection and identification of invertebrates, vertebrates, microbes, and plants found within springs and caves and surface-associated spring discharge areas. Understanding karst flow regimes may require computer-modeling to fully understand these systems.

Some suggestions for getting this work done include the following: encourage student research from accredited Universities that have Masters and PhD programs. Many times this research is funded through University or other sources and provides managing units with leading-edge research in cave and karst fields; seek out local knowledge for not only the managing unit but for areas that may be contributing to the recharge areas off of the unit. Locals have spent their lifetimes in the area and can provide a wealth of information concerning spring and cave locations and other important contributing resources; use volunteers whenever possible. Many times, the cave survey and science communities can provide time and effort to document cave and karst areas. There are a number of very talented individuals and groups that have a passion for cave and karst resources and are willing to provide excellent work for access to some of their favorite places.

Infrastructure Concerns

Infrastructure and human activities surrounding that infrastructure tend to present the most serious concerns for long-term protection of cave and karst resources. These concerns are both internal and external to the managing unit. All structures have the potential to present problems, while some are worse than others. Some of the structures include roads, various buildings, the utilities that connect to those buildings, and parking lots. Aging buried sewer lines can deliver raw sewage directly into cave and karst systems. There have been numerous examples of this problem over the years, especially where commercial cave operations have been placed directly on top of their cave. One of the worst examples came about when thousands of worms, eating sewer sludge between the broken sewer line and the guided tour passages a few tens of feet below the surface, began falling out of the ceiling and onto visitors along the paved, lit trail of the commercial cave below. The adage "out of sight, out of mind" continues to be a term that describes a number of people's views on things under the ground, such as caves. A manager of lands with caves and karst cannot afford to take this view. Human infrastructure and activities can destroy natural processes and ecological systems, contaminate water sources, and impact financial well-being, as in the case of the commercial cave above.

Associated activities can also be of major concern to cave and karst resources. Examples of these activities include, but are not limited to: pesticide and herbicide use, painting activities, and auto-repair. Scrapping a house or building before it is painted is a common activity. Catching the paint chips and discarding them in a proper manner may help protect cave and karst areas for the long-term. If the house or building is older, those paint chips could easily contain large quantities of lead and left on the ground to slowly deteriorate, this lead would infiltrate down into the cave below. Numerous commercial operations use very serious items such as paint thinners, degreasers, and other toxic materials. Improper storage and use along with improper disposal of these types of materials can cause serious contamination problems for caves and groundwater.

Mining activities, including those associated with oil and gas discovery and production, can cause irreparable damage to cave and karst resources. Mine tailings can hold minerals and chemical compounds that would not normally be exposed to rain and other weathering elements. Runoff from mine tailings can enter surface streams or sinkholes and eventually be transported into cave entrances or into karst water systems. Either way, this runoff can bring contamination to these resources. Drilling for oil and gas in karst areas or around caves can do damage and introduce contamination as well. This damage can be physical such as when a well-bore intersects a cave passage. The drilling fluids empty directly into the intersected cave passage. When a cave is intersected during the drilling process, the drill bit drops and drilling comes to a halt. The easiest way to continue drilling is to pump concrete and other materials into the void space until it fills up. The drilling rig operator can then drill through this filled-in material. In many cases, the void is small and there are no real problems. However, the intersected void space can be very large. Companies have been known to pump materials into the void space for a number of days without filling in the space. When the company cannot fill the void space they must place casing in the well-bore and the void they have intersected, before continuing downward. So in some cases there are large cave passages or rooms containing a very large pile of concrete and other materials with a cased well-bore coming down out of the ceiling to the top of this pile. The cave passage cannot have fared very well in this situation. One other problem with drilling concerns the type of pipe used to relay oil or gas to the surface. Because of cost, most drilling pipes are made of mild steel. This allows them to survive most subsurface conditions. Over time though, this pipe can deteriorate, particularly where a crack or small fracture in the bedrock has been exposed to the pipe. In the case of a well producing high-pressure natural gas, once a pipe has been compromised, that high-pressure gas can move into fracture systems and directly into a cave system. Such was the case in a cave near Artesia, New Mexico a number of years ago when several young boys went into a cave using candles or some other open flame. When they entered the cave their light source ignited gas that had filled the cave from a leaking well-pipe, causing an explosion that killed the boys. This could happen to larger caves as well.

Catastrophic events such as structure or automobile fires and major spills are another problem that can cause contamination of resources. An evaluation of resources should also include knowledge of structures and the potential for catastrophic events. They do occur and the more a manager can be aware of the potential for problems, the better that manager can be concerning keeping contamination from reaching cave and/or karst areas. A tragic example of this type of event occurred in Austin, Texas more than 20 years ago when a large gasoline truck was filling buried gas tanks with gasoline at a service station. This service station sat on the very edge of a dry sinking stream within the Edward's limestone. A small accident with a connection hose led to a large fire and explosion. Within minutes, the bulk of the gasoline (thousands of gallons) from the tanker truck spilled directly into the sinking stream. By the time a clean-up crew arrived on scene, most of the gasoline had disappeared into the limestone aquifer. Knowledge of the resources, including structures and the potential for catastrophic events, can help keep structures from being placed in sensitive areas and can help prevent these types of events by developing mitigation factors to keep accidents from becoming a catastrophic event.

Springs and Caves

Both springs and caves can be easily impacted from manmade structures and activities. Karst springs are the downstream outlet for a hydrologic system. Depending on numerous factors, including the quantity of water that flows out of a spring, these hydrologic systems can be fairly small or extremely large with drainage basins for individual springs covering huge areas. Big Spring in Ozark National Scenic Riverways is one of the largest karst springs in the United States, with an average flow of about 440 cubic feet per second. Though not totally known, the recharge area for this spring could easily be in the hundreds of square miles. There was great concern for this spring in recent years because of a proposal to mine lead within its recharge area. Eventually this proposal was denied because of the potential to contaminate Big Spring and the nearby Current River.

Understanding the hydrologic and geologic settings for springs and caves is important, as illustrated by the proposal to mine lead in the preceding paragraph. There are other concerns as well that need attention. These include knowing the infrastructure and activities that are found within the recharge area of a given spring or on the surface in the vicinity of a cave passage, monitoring the water-quality and the amount of flow on a consistent basis from springs and, of great importance, identifying and monitoring the aquatic and terrestrial ecosystems that are associated with these springs and caves. Numerous karst springs and caves contain rare and endemic species. These species rely on uncontaminated water and areas to survive. Monitoring these species, the quality of water, and other factors related to caves can provide a way to detect contamination issues and problems.

Planning and NEPA Compliance

Following through with the planning process is a critical last step in the long-term protection and conservation of cave and karst resources. Many agencies receiving federal funding have to follow the rules and regulations of the National Environmental Policy Act of 1970. This law mandates a review of federal actions and requires public input for many projects. Taking the time to get approved projects in place can mean the difference between a successful attempt to mitigate identified problems and not being able to make corrective actions to protect cave and karst areas. An example of a success story lies within Carlsbad Caverns National Park and the removal of the pavement from most of the Bat Flight parking lot located immediately adjacent to the entrance to Carlsbad Cavern. This parking lot was developed in the 1930’s and a study done in the mid-1990s showed that it was a primary source of contamination to the cave below. It took 19 years from the identification of the problem, through the study of, to an approved Environmental Assessment (EA), to the removal of the pavement to complete this project. Without an approved EA in place, the project would not have been considered or completed.

A manager of cave and karst areas must be vigilant, diligent, and thorough. There can be a lot of competing interests and reasons to not make changes that help protect and conserve cave and karst areas. But for managers charged with the health and vitality of natural areas, understanding these complex resources through scientific research and education, understanding the types of infrastructures and activities that occur within the affected area, and the development of mitigation measures through a public planning process can lead to the long-term protection and conservation of cave and karst resources.

Cave and Karst Resources in West-Central Florida, USA: Implications For Management, Education, And Research

Jason S. Polk1, Grant L. Harley2, Leslie North1, Philip Reeder3

1Hoffman Environmental Research Institute, Department of Geography and Geology, Western Kentucky University, Bowling Green, KY 42101
jason.polk@wku.edu, 270-745-5015

2Department of Geography, University of Tennessee, Knoxville, TN 37996
3Department of Geography, Environment, and Planning, University of South Florida, Tampa, FL 33620

Abstract

The active management of karst features, such as cave systems and springs, is virtually non-existent within the karst landscape of west-central Florida. Before sound management policies can be drafted, implemented, and enforced, stakeholders must first have knowledge of the distribution and importance of karst resources, and the human-environment interactions impacting them. Here, we present various methodologies combined in a concerted effort to collect, analyze, synthesize, and disseminate karst resource information using a geographical approach, including development and implementation of a cave resource inventory geodatabase, GIS mapping, cave survey, hydrologic inventory, and education and outreach activities about human-environmental interactions, focusing on an holistic approach toward cave and karst management and protection policies. We examined the karst landscape of west-central Florida on both public and private land, and analyzed these data to determine sensitive and vulnerable areas related to groundwater and cave resources. These activities culminated in three main goals, which include a cave and karst management plan for the Withlacoochee State Forest, creation of the Dames Caves Educational Preserve, and collaboration to develop karst groundwater publications with the Southwest Florida Water Management District in west-central Florida. This research is ongoing and will result in the creation of an informational avenue that will serve as a link between researchers, land managers, and the public to better understand and protect karst features in the study area.

The Role of the National Cave and Karst Research Institute in Cave and Karst Management

George Veni
Executive Director
National Cave and Karst Research Institute
400-1 Cascades Avenue
Carlsbad, New Mexico 88220-6215 USA
575-887-5517
gveni@nckri.org

Abstract

In the 2011 book *Karst Management*, I wrote a chapter describing six roles of the world's twelve national cave and karst institutes in cave and karst management. Here I describe the purpose, status, and goals of the U.S. National Cave and Karst Research Institute (NCKRI) relative to those roles:s

- **Research.** NCKRI has an Applied Science Program but little staff. Research is conducted opportunistically, currently focused on hydrogeological and geophysical studies, until additional staff is hired.
- **Education and Publication.** NCKRI's Strategic Education Plan is focused on resource management. Rigorous implementation of the plan will begin once work on key education tools (website, museum exhibits, etc.) is completed in 2012. Three publications series are established.
- **Independent Advice and Arbitration.** NCKRI is a clearinghouse of information and insight. Technical advice is given through casual (e-mail, telephone, in-person) and formal (committee) means.
- **Data Archiving.** The Karst Information Portal is NCKRI's archive for all cave and karst data. The information is freely available at www.karstportal.org. Additional data resources are added daily, and more resource management tools await development.
- **Funding Generation and Granting.** NCKRI funding is currently focused on establishing the Institute, its facilities, staff, equipment, and programs. External support is limited and will increase after NCKRI's core needs are met.
- **Collaboration Facilitation.** The needs of cave and karst management exceed the ability of any one person or organization. NCKRI actively builds and supports collaborations to maximize results with the limited resources available.

Introduction

The National Cave and Karst Research Institute (NCKRI) of the United States of America was created by the U.S. Congress in 1998 in partnership with the State of New Mexico and the City of Carlsbad. NCKRI's enabling legislation, the National Cave and Karst Research Institute Act of 1998, 16 U.S.C. §4310, identifies NCKRI's mission as to:

1) further the science of speleology;
2) centralize and standardize speleological information;
3) foster interdisciplinary cooperation in cave and karst research programs;
4) promote public education;
5) promote national and international cooperation in protecting the environment for the benefit of cave and karst landforms; and
6) promote and develop environmentally sound and sustainable resource management practices.

Initially an institute within the National Park Service, NCKRI is now a non-profit 501(c)(3) corporation that retains its federal, state, and city partnerships, and is administered by the New Mexico Institute of Mining and Technology (aka New Mexico Tech).

NCKRI's creation and mandates reflect the growing awareness about karst areas. They cover a significant percentage of the Earth's land surface and contain complex, diverse, important, yet vulnerable natural resources that need specialized knowledge for effective management. In Veni (2011), I wrote the first report to comprehensively evaluate national karst research institutes internationally, and identified and described their six roles in cave and karst management:

1) research
2) education and publication
3) independent advice and arbitration
4) data archiving
5) funding generation and granting
6) collaboration facilitation.

In this paper, I describe NCKRI's purpose, status, and goals relative to those roles. Unless otherwise cited, the sources of information and for elaboration for the discussions below see NCKRI's recent annual reports (NCKRI 2008, 2009, 2010, 2011a).

Research

NCKRI has a Basic Research and an Applied Science Program but only one employee dedicated solely to research. Dr. Lewis Land is a hydrogeologist who splits his time between basic and applied research, depending on which program has a funded project. Additional research personnel are Dr. Penny Boston and me. Dr. Boston's focus is as NCKRI's Academic Program Director, and the students and student research she supervises. I serve as NCKRI's Executive Director and focus on administrative issues, working on multidisciplinary karst issues only when time allows.

Much of NCKRI's research is opportunistic. While NCKRI does apply for grants and contracts, it is more productive when working on projects offered rather than spending substantial time applying for grants and contracts it might not receive. Most research conducted by Dr. Boston and her students is basic, unraveling the fundamental principles of cave and karst geobiology, geomicrobiology, and hydrogeology. Some of their research is applied, such as for potential industrial and medicinal uses of microbes and toward the search for extraterrestrial life, but little currently addresses cave and karst management issues.

Most management research by NCKRI has been led by Dr. Land and has focused on water supply, flooding, collapse, and tourist management issues. Examples include:

- **Water supply.** Working with the New Mexico Bureau of Geology and Mineral Resources, NCKRI has studied seasonal water level fluctuations in the karstic Roswell Artesian Aquifer of New Mexico. This project allows a better evaluation of the effects of water well pumping on groundwater availability for human use and from springs at the Bitter Lakes National Wildlife Refuge for wildlife (Land and Newton, 2008). NCKRI plans to build on this work locally and in other areas to better understand karst aquifers that serve as water supplies in arid regions.

- **Flooding.** In January and February 2011, NCKRI joined a humanitarian karst flood control project with Engineers Without Borders. They assessed the feasibility and potential problems in excavating a channel to divert flood waters around the village of Las Cruces in north-central Guatemala. All surface drainage in the area flows into a cave in the middle of town. Conversion of the surrounding forest to agricultural land now results in floods that exceed the cave's drainage capacity. Flooding up to 3 m results from overflows at the entrance and groundwater rising out of wells. The proposed diversion channel could intersect caves, or result in collapse into caves after construction, which would negate its meditative effects. Dr. Land supervised the excavation of 24 test pits to determine depth to bedrock (logistical factors prevented use of NCKRI's geophysical equipment). Coupled with observations of the local geology, Dr. Land assessed the potential for the proposed channel to intersect or collapse into shallow caves.

- **Collapse.** In 2008 and 2009, three anthropogenic karst sinkhole collapses occurred in southeast New Mexico and west Texas. Some had diameters greater than 110 m and depths of more than 45 m. The sinkholes resulted from the collapse of cavities created by brine wells that solution-mined salt in the Permian Salado Formation roughly 140 m below ground level. NCKRI conducted electrical resistivity surveys adjacent to two of the sinkholes as a proof-of-concept study on the use of electrical resistivity methods for investigating brine-filled cavities associated with solution mining. NCKRI was later contracted by the State of New Mexico to geophysically characterize a similarly large cavity within the City of Carlsbad to determine its potential for catastrophic collapse and to help guide prevention efforts (Land and Veni, 2011).

- **Tourist management.** In 2011, the National Park Service (NPS) contracted NCKRI to identify all NPS properties located in cavernous and/or karstic areas. NCKRI will then evaluate generally those park units' cave and karst research and educational/interpretative programs, and any broad resource management problems or potential problems that may exist due to internal tourist management or external causes of resource stress. This study will help the NPS prioritize which parks or topics require the most urgent attention. The study will be complete by the end of 2012.

Education and Publication

Education, within the context of how it is organized and conducted by cave and karst institutes, is defined within three broad categories (Veni, 2011):

- Technical Education. Within this category are seminars, lectures, workshops, and classes for undergraduate to professional level audiences interested in advanced, specialized information necessary for professional jobs that involve caves and karst. These programs provide formal credit for participation that may be applied to a degree and/or to continuing education requirements for a job or a professional or research license. NCKRI offers such courses specialized in cave and karst topics through its Academic Program at New Mexico Tech, although none currently focus on management issues.

- **Public Education.** In this context, public education involves lectures, workshops, classes, and entertaining events that provide general, simplified or non-technical, cave and karst information for the public. This includes presentations to pre-college students because of the technical level of the content. The purpose of public education is to elevate society's general awareness of caves and karst, including their importance and vulnerability to human activities. While most cave and karst institutes provide public education through lectures, brochures, and books, NCKRI is one of only three with education programs that make public education a major priority. Cave and karst management is fully integrated in NCKRI's Education Program, as reflected by this statement defining the program's foundation: *Maintaining or restoring the integrity of cave and karst systems depends upon public understanding of their importance both to people's daily lives and as repositories of significant biological, geological,* *hydrological, paleoclimatological, and cultural resources* (NCKRI 2011b). NCKRI has hired an Education Director, Dianne Gillespie. She works to better include cave and karst instruction at universities, as well as through the gamut of public education methods. Key efforts of her Education Program are to add cave and karst knowledge into the national education standards, and to work cooperatively or expand on existing teach-the-teacher programs to more quickly and widely disseminate karst information.

- **Publications.** Publications are not usually considered an education category but an education tool. They are listed here as a category because they constitute an important program of nearly all cave and karst institutes. "Publications" are not limited in this context to printed books, journals, and newsletters. They include digitally-produced media that relay similar information such as websites, videos, interactive learning programs, and webinars. Publications reach out to people of all ages and knowledge levels, and are not restricted to only the technical or public education categories. NCKRI's printed publications include three series, all of which may include management topics. Additionally, NCKRI's new website has information about NCKRI's Applied Science and Education programs.

Elaborating on NCKRI's public education efforts, NCKRI's National Cave and Karst Museum is currently under development. It will serve as a starting point for NCKRI's Strategic Education Plan. Rigorous implementation of the plan will begin once key public education tools are fully developed, such as the website and museum exhibits and curriculum. Additionally, straddling the line between Technical and Public Education, NCKRI is beginning to host conferences at its headquarters and beyond. In 2011 it was given management of the prestigious *Multidisciplinary Conference on the Impacts of Sinkholes and the Engineering and Environmental Impacts of Karst* conference series.

Independent Advice and Arbitration

A poorly publicized and often private function of karst research institutes is to provide expert advice and insight on questions involving caves and karst. This service is based solely on an institute's existing experience and information. It is separate from the institute's research role, where the institute might conduct studies to resolve an issue. The topics in these circumstances are almost always related to cave and karst management and fall into one or more of three categories: planning, problem-solving, and dispute resolution.

Employees of karst research institutes often serve on technical committees to assist in creating research programs and management plans for caves and karst areas. NCKRI is a clearinghouse of cave and karst data and insight. Its employees are often sought to provide information and ideas and to review reports. Examples of NCKRI's committee service involving karst management and related planning include:

- I sit on the Aquifer Science Advisory Panel of the Edwards Aquifer Authority (a regional governmental agency in Texas, U.S.A., charged with the protection, study, and management of that major karst aquifer), to review research and proposals by the agency and advise on improvements for the agency to better meet its goals.
- Dianne Gillespie works on a U.S. Forest Service (USFS) cave and karst management plan writing committee; the plan is expected to become the USFS national cave and karst management plan.
- Dianne Gillespie also serves on a committee of the Carlsbad Municipal Schools; the committee gained the City of Carlsbad recognition as one of the "Top 100 Communities for Young People" by the America's Promise Alliance in 2010.
- Dr. Penny Boston is a member of the NASA Advisory Council Committee on Planetary Protection and the National Academy of Sciences COMPLEX committee.

Most times, this type of assistance is informal, undocumented, and provided through personal communications in response to specific questions.

Cave and karst institutes also participate in problem-solving missions. The situations frequently require urgent action and are often potentially or truly legally and/or politically sensitive. Information on an institute's involvement is generally unpublished or not published within the readily accessible literature. For example, NCKRI staff serve on a committee to evaluate the risk of a potential catastrophic sinkhole collapse and to explore what can be done to prevent it.

Based on a literature review and personal communications, which cannot be cited due to legal issues, cave and karst institutes seldom function as arbiters of disputes. NCKRI has no legal authority for arbitration and does not function in this capacity.

Data Archiving

NCKRI maintains a small but steadily growing library of books, publications, and maps, mostly donated by retired cavers and cave scientists. Cataloging of the library is an upcoming NCKRI project; a count of publications and topics is not yet available. The problem with traditional paper-based libraries and archives is that karst science is an intrinsically multidisciplinary field of study that is poorly indexed and difficult to access. While there is a significant body of internationally useful literature, important works remain largely unknown or inaccessible. Some of the more difficult-to-access documents include maps, databases, technical reports, graduate theses and dissertations, images, video, and government publications. Also, karst-related documents published in less-accessible languages are hard to retrieve or find. Consequently, NCKRI has also developed a virtual library, the Karst Information Portal or KIP (www.karstportal.org), with partners from the University of South Florida, University of New Mexico, and the International Union of Speleology. Access to KIP is international and free with an Internet connection.

KIP was created in 2007 and designed specifically to solve the information access and management problems of traditional libraries. It provides an open-access global portal as an on-line gateway to karst information and services. About 6,000 documents on all cave/karst-related topics were available via KIP in mid-2011. They include theses, dissertations, databases, bibliographies, images, gray literature, maps, and

50 journals from 12 countries. Considerable information is available on cave and karst management, including the proceedings of the National Cave and Karst Management symposia. Additional data resources are added daily.

KIP's usage is increasing dramatically, doubling annually since 2009. However, KIP is currently used for and primarily known as a virtual library. It is in fact created as a platform to attach a wide array of versatile research tools. The virtual library is only one such tool. Oral histories of cave scientists and a collection of scanning electron microscopy images in a format where researchers can collaborate and exchange ideas are other tools available through KIP. A karst mapping tool and others are in development. Contributions of new tools and ideas are encouraged.

Funding Generation and Granting

In principle, NCKRI should readily generate funds to build its research programs and to support others. Unfortunately, even though NCKRI receives more annual funding than most karst research institutes, that is not currently the case. During its early history, NCKRI sponsored three visiting scholars, and most years NCKRI has financially supported at least one cave and karst conference. Presently, NCKRI's funds must be directed inward to build its headquarters, buy equipment, and hire additional staff, all of which are critical steps to secure NCKRI's financial growth and security. Also, the job of NCKRI's newest employee, Advancement Director Ann Dowdy, is to increase and diversify NCKRI's funding sources through grants, gifts, membership programs, and related means. Once NCKRI's critical start-up construction, purchases, and hiring are completed, a grants program will be established and other ways created to direct funds outward to support all forms of cave and karst research.

Collaboration Facilitation

Collaboration with other institutes, organizations, governmental agencies, and individuals is crucial to NCKRI's growth and long-term success. This synergy is not only efficient, but produces results that exceed the sum of each collaborator's contributions. NCKRI actively builds and supports collaborations to maximize results with the limited resources available. Its collaborations can be defined by four general categories:

- Volunteers. In 2012, NCKRI will formally establish a volunteer recruitment and activity program. While volunteers can produce a great deal of work for an organization, they also require considerable staff time to make sure they are properly oriented, trained, supported, and appreciated. Until recently, NCKRI didn't have the time or resources to support a volunteer program, but it has been fortunate to have several people give assistance as needed for a variety of tasks. During the opening of NCKRI Headquarters in May 2011, NCKRI's Board of Directors gave the Institute's first awards to two exceptional volunteers. Dr. Kevin Stafford received the Meritorious Service Award, given for exceptional volunteer service on a specific NCKRI project or activity, which in this case was as Editor-in-Chief in 2009 for *NCKRI Symposium 1, Advances in Hypogene Karst Studies*. Dr. Patricia Seiser received the Distinguished Service Award, NCKRI's highest volunteer award, given for outstanding long-term volunteer service to NCKRI. Dr. Seiser volunteered almost daily at NCKRI for more than four years during its critical formative years and provided vital assistance in countless ways.

- **Conferences.** In recent years, fewer conferences have been planned by single organizations. Through collaboration and pooling of resources, it is possible to create an event larger or better-executed than a single organization's ability to host. During its early years, NCKRI primarily offered financial sponsorship to conferences, lacking the staff to participate substantively in their operation. That is now changing. NCKRI is jointly organizing the tentatively titled *Carbon and Boundaries in Karst* symposium with the Karst Waters Institute in January 2013 and the *Karst Interest Group Workshop* with the U.S. Geological Survey in April and May of 2014. NCKRI will host the 2013 *National Cave and Karst Management Symposium* at its headquarters in Carlsbad, New Mexico, while partnering with several agencies in the area that manage caves and karst. Even though NCKRI was given management of the aforementioned *Multidisciplinary Conference on the Impacts of Sinkholes and the Engineering and Environmental Impacts of Karst*, it is maintaining and expanding the conference's organizing committee—experts who represent multiple organizations, agencies, and universities.

- **Projects.** By virtue of its location, logistics, and relatively young age, NCKRI's collaborative projects involving cave and karst management have mostly been with other organizations in New Mexico, like the New Mexico Bureau of Geology and Mineral Resources, and federal agencies. This trend is changing, as seen with some of the projects previously mentioned like the Karst Information Portal and the NPS evaluation project, where NCKRI has subcontracted the Mammoth Cave International Center for Science and Learning for assistance. Potential projects are currently in the discussion phase with potential national and international partners. This trend is expected to grow as NCKRI satisfies its core needs of headquarters completion (while the headquarters is open, some areas are unfinished and the museum exhibits have yet to be created and installed), equipment acquisition and additional staffing, and is able to spend more resources on projects.

- **Agreements.** As indicated above, NCKRI wishes to collaborate on conferences, projects, and other activities whenever possible to improve productivity. In 2010, NCKRI signed memoranda of understanding (MOU) with the Emil Racovita Institute of Speleology (ERIS) in Romania, the Karst Research Institute (KRI) of Slovenia, and the Ukrainian Institute of Speleology and Karstology (UISK). These MOUs formalized a foundation for closer inter-institute cooperation and an exchange of information, publications, students, and scholars, plus open access to conferences and workshops. They promote cooperation in developing research, management, and educational projects, programs, and conferences when practical. NCKRI is actively pursuing additional formal agreements with other national and international organizations.

Conclusions

I am often asked, "On which type of research will NCKRI focus its research programs?" My answer is pragmatic, "Water and environmental management." While many fields of study will yield tremendously important findings for basic science and practical application, I expect that most funding opportunities will be in those two areas. Karst aquifers are the most vulnerable to pollution, and karst regions pose a complex set of ecosystem and engineering challenges unlike any seen in other terrains. When ERIS was established as the world's first national karst research institute in 1920, the following terms were largely unknown: carrying capacity, endangered species, groundwater contamination, human-induced land subsidence, overdrawing of aquifers, sustainable usage. They are commonly used today in reference to caves and karst, and I expect they will drive many of NCKRI's research programs.

NCKRI will continue research into the theoretical aspects of cave and karst development. The topics have not been exhausted; they have expanded from newer and far more in-depth insights offered by modern technology. They are also important in solving management problems and some will be funded by management research programs. But "problems" also require mandates to fix. As NCKRI fully matures into a well-recognized authoritative body, I expect it will work increasingly with government agencies and legislators to address environmental management problems in karst and improve policies for the prevention and remediation of karst-related problems. Public support for such efforts should increase as NCKRI's Education Program gains traction.

"Strength in numbers" is a long-held truism that NCKRI pursues. In 2010, Dr. Tadej Slabe, Executive Director of KRI, began developing the "Karstological Academy," and worked with me and Dr. Alexander Klimchouk, UISK Executive Director, on its mandate and structure. Following an organizational meeting in 2011, it was renamed the International Academy of Karst Sciences (IAKS). Its purpose is to serve as a consortium of cave and karst research institutes, working together to facilitate better understanding of caves and karst internationally in society and the scientific community, promote karst research and good research practices for karst, and further cooperation and partnership through the sharing of resources, results, experiences and opportunities. Essentially, IAKS will be an organization of karst research organizations that will supplement, not compete, with any cave exploration, management, education, or research group. NCKRI supports and will be an involved member of this initiative.

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Lincoln National Forest Revises a Cave Management Program

Jason Walz, Cave Specialist,
Lincoln National Forest
jawalz@fs.fed.us

Abstract

Lincoln National Forest is revising its Cave Management Program. The program currently complies with the White Nose Syndrome Interagency Response Plan for New Mexico and follows the decontamination requirements of the Unites States Fish Wildlife Service. The plan provides for smart recreational use through a permitting system while monitoring human impact and ecosystem resilience. The Lincoln National Forest program allows only caves that have no significant bat population to be opened. As more data is collected about the caves, Lincoln National Forest hopes to provide additional recreational access while fulfilling its obligation to conserve bat habitat and other cave resources.

The Lincoln National Forest (LNF) in the southeastern portion of New Mexico is home to over 200 discovered caves. LNF is in the process of revising its Cave Management Program. The program currently complies with the White Nose Syndrome (WNS) Interagency Response Plan for New Mexico and follows the decontamination requirements of the Unites States Fish Wildlife Service (USFWS). The plan provides for smart recreational use through a permitting system while monitoring human impact and ecosystem resilience. LNF's Cave Program aims to meet the needs of the public while following USFS rules, protecting bats and preventing human-caused spread of White Nose Syndrome.

You find the greatest concentration of caves at the southern end of the LNF. This concentration is located squarely between two magnificent national parks: the Guadalupe Mountains National Park to the south and Carlsbad Caverns National Park to the east. A national forest sandwiched between two national parks in wild cave country creates a unique situation for LNF. With this in mind, the LNF and its Regional leadership have made a series of distinctive management decisions over time. In the early 1970's, LNF prohibited entry into caves without a cave permit (Lincoln, 1972). This was and still is uncommon in the U.S. Forest Service, but the decision reflects the policy of both bordering parks, which have similar cave resources. LNF also decided to "work with grottos… to identify where cave entry should be allowed by the public…", as mentioned in the document '*Decontamination Procedures for Use on National Forest System Lands*'. This document provides guidance to all national forests on the subject of complete cave closures or an active cave access management plan. LNF has chosen the latter; that cave entry is "necessary or allowable" and has developed a WNS system to "ensure [that] decontamination protocols are understood and followed (USDA, 2010)". The USFS Southwest Region, which includes LNF has also made some unique, progressive decisions that have kept caves open. The Southwest Region, alongside other agencies, developed a WNS Interagency Response Plan for New Mexico. The plan did not call for complete closure found in other Regions, but instead included, "Recreational caving trips may be allowed within known caves that are not significant bat roosts, provided that requirements are followed, including appropriate decontamination and gear dedication procedures (USFS, 2010)". By following this interagency agreement and by enforcing its cave permit system. LNF is in an ideal situation to continue to offer recreational caving opportunities while ensuring to the greatest extent possible that bat populations are protected.

LNF plans that allow cave access also contain strict requirements to ensure that USFWS WNS decontamination procedures are followed. The intent of these USFWS rules is to prevent any human-caused jumps of WNS across the country. A repeated question facing the Forest is whether or not people accessing caves are really following the procedures. LNF is taking steps similar to those taken by other Forests and agencies. The most important step is communicating WNS procedures in an easy-to-understand manner. LNF has developed a simplified guide to WNS procedures and sends the information out in advance. Before obtaining a cave permit, all participants must read this information and sign a statement confirming they understand and will follow the procedures. The day of the cave visit; they also must sign the permit verifying that they have followed the WNS procedures before that specific trip. In addition, the Trip Leader who obtains the cave permit is responsible for onsite inspection of decontaminated gear and for enforcing procedure during the trip. By sending out detailed information early and requiring compliance through cave permits and Trip Leaders, LNF is ensuring that USFWS WNS decontamination procedures are understood and followed.

Both the WNS Interagency Agreement for New Mexico and the USFWS Decontamination Procedures has provided a framework for LNF to develop recreational cave access. The Interagency Agreement answers the question of, *"Which caves should be closed to recreation for bat protection?"* by providing a criteria for significant bat cave identification and closure. LNF has closed all caves that have colonies of bats in any season as well as caves that contain small groups of specific species. The USFWS provides guidance for delineating clusters of caves that are close enough together that they can be treated as one area for WNS decontamination (US Fish, 2011). LNF has identified a cave-cluster in the southern end of the Guadalupe Ranger District that allows the public to visit multiple caves within the same weekend. This focuses on providing a true barrier to human-caused spread by thorough decontamination at home, while still allowing the public to camp and visit caves in much the same way they have in the past. Lincoln National Forest's Cave Program is built on the WNS Interagency Agreement for New Mexico and the USFWS Decontamination Procedures, providing a foundation for recreational cave access in the age of WNS.

The dual focus of recreational opportunities and cave ecosystem conservation is built on the idea of *active* cave management. In contrast, a passive management system generally means simply opening gates seasonally, providing general rules, and directing potential visitors to the National Speleological Society (NSS) for cave access. While this does provide some conservation by the inclusion of NSS members, little knowledge can be gained concerning cave use, misuse, or compliance with this type of management plan.

LNF changed to an *active* cave management almost 40 years ago by forming a cave permit system, hiring Cave Technicians yearly, and recently by hiring a Cave Specialist. With this dedicated cave management staff and a cave permit system, LNF collects data on cave use, they organize groups of volunteers for management and restoration projects, they represent the USFS at regional and national events, and they provide leadership in the prevention of human-caused spread of WNS.

Another aspect of LNF's cave management style is recruitment and advancement of volunteers. LNF provides a step-by-step process for the general public to gain experience through recreation, teach others as a Trip Leader, contribute to the USFS as a volunteer, and organize others as an Expedition Leader. Many National Forests that are restricting recreation are cutting this first step. LNF has found recreation to be important to developing teams of volunteers with the experience to complete management tasks. Experienced recreationists that want to lead others into caves can easily become Trip Leaders. The Basic Trip Leader can be obtained by anyone who has successfully completed a cave trip in the Forest with a Trip Leader. This provides a reference check and an opportunity for recreationists to share the responsibility of cave conservation and WNS prevention. With more experience, recreationists can eventually become an Advanced Trip Leader, which opens access to more caves on the Guadalupe Ranger District. After gaining this experience, many continue by becoming volunteers and completing science and management tasks. Natural leaders may emerge that are willing to become Expedition Leaders, which can completely take over volunteer projects. Some national forests have successfully handed over their entire cave management to a strong Expedition Leader with a well-organized group of volunteers from the Cave Research Foundation or the NSS. Volunteers at LNF are organized into expeditions and complete specialized tasks with training provided by the LNF. The goal of this volunteer training program is to improve the quality of cave-data collected to a professional level and to provide volunteers with increasing input and responsibilities similar to a development plan for employees.

Active cave management may be the only way that national forests across the country can effectively provide recreational opportunities, while providing maximum conservation for bats and other cave resources. Unfortunately, some national forests are responding passively to pressure to protect bats from WNS by closing all caves to the public. Cavers, like most visitors, only come to a national forest for a specific type of activity; therefore, the closing of caves across the country has effectively closed large portions of these lands to these national lands recreationists. The USFS Southwest Region, which includes LNF, has not called for complete cave closures but has instead developed interagency rules defining targeted significant bat cave closure. Within this Regional support, LNF is revising an innovative recreation plan allowing cave access and preventing human-caused spread of WNS.

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The Geography of Karst

James E. Kaufmann
U.S. Geological Survey
Earth Resources Observation and Science Center (EROS)
jkaufmann@usgs.gov, 573-578-8931

Abstract

Effective management of karst resources and assessing the hazards and vulnerabilities of karst requires a thorough understanding of the geography of karst. Geography tries to answer such fundamental questions as "what is it, where is it, and how does it interact with its physical, biological, and cultural surroundings?" There is a wide variety of definitions for karst, but most karst scientists will agree that significant secondary porosity and hydraulic conductivity—especially vertical—are key components. Mapping and describing karst landscapes, however, are much more difficult tasks. Karst features are not always obvious and, as in the case of losing streams, not often depicted on maps. Advanced mapping methods, such as high resolution digital elevation models derived from lidar, can be used to locate and quantify features which fail to meet the normal minimum mapping standards for the U.S. Geological Survey's 1:24,000 scale topographic map series. Advanced analytical techniques use combinations of existing data sets to identify and classify regions of karst development but rely on data typically depicted on maps or gathered for more general purposes. Even with these advanced techniques, describing how karst interacts with its surrounding areas—especially the human environment—is a daunting challenge. Mapping the recharge area for a spring or group of springs requires intensive field work. Assessing catastrophic soil-cover collapse hazards often relies on interpolating or extrapolating data beyond their range of validity. With increasing development pressure on karst regions and greater demand for fresh water resources, a thorough understanding of the geography of karst is becoming increasingly important.

Alpine Karst in Utah - An Overview

Lawrence E. Spangler
U.S. Geological Survey, 2329 Orton Circle
Salt Lake City, Utah 84119,
spangler@usgs.gov

Abstract

Alpine karst areas in Utah are located primarily in the Uinta Mountains and Bear River Range, and localized areas within the Wasatch Range, all of which are part of the Middle Rocky Mountains physiographic province. In these ranges, karst features and associated groundwater flow systems are developed in limestone and dolostone ranging in age from Cambrian to Mississippian. Karst and vulcanokarst systems also are present in Tertiary-age limestone and basaltic volcanic rocks in the southwestern part of the state on the Markagunt Plateau where dissolution of the Claron Formation and subsequent collapse of the overlying basalt have resulted in extensive sinkhole development.

In the Uinta Mountains, alpine karst systems are developed primarily within Mississippian-age limestone, which crops out on the flanks of this east-west trending anticlinal structure. In the southeastern part of the range, surface water originating on the sandstone core of the uplift sinks along the outcrop band of the limestone and moves down dip through extensive cave systems such as Big and Little Brush Creek, to discharge at large springs. Lateral movement of groundwater between adjacent surface-water basins in this area and along bedrock strike on the northern flank of the range has been documented by dye-tracer studies, which include some of the longest dye traces in the western United States.

Alpine karst in the Bear River Range is developed within Cambrian to Devonian-age limestone and dolostone, and contains the state's deepest caves. Groundwater that is recharged primarily by snowmelt runoff discharges from large karst springs along the Logan River, the principal base-level stream in the northern Utah part of the range. The Logan Peak syncline, a major regional structure bisected by the river, has a significant influence on groundwater movement in this part of the range. On the basis of dye-tracer studies, delineated groundwater basins for the major springs appear to be areally and stratigraphically separated, and groundwater travel times from recharge areas as much as 1,150 meters higher than and 13 kilometers from the springs are less than four weeks.

Introduction

Utah is characterized by a wide variation in geography and geology, largely because the state lies at the junction of three major physiographic provinces – the Basin and Range, the Middle Rocky Mountains, and the Colorado Plateau (Figure 1). Although karst geomorphic features are developed throughout these regions where carbonate rocks lie at or near the land surface, active karst hydrologic systems are developed primarily in alpine areas where abundant precipitation is present, mostly in the form of snow. These areas include the Bear River Range in northern Utah, the Uinta Mountains in northeastern Utah, and localized areas within the Wasatch Range; all of which are part of the Middle Rocky Mountains province (Figure 1). In these ranges, shallow groundwater flow systems are developed in limestone and dolostone ranging in age from Cambrian to Mississippian. Karst flow systems also are present in Tertiary-age limestone that underlies basaltic volcanic rocks in the southwestern part of the state on the Markagunt Plateau (Figure 1). In addition, aquifers developed within carbonate rock are present in many of the mountain ranges that make up the Basin and Range province, which covers the western one-third of the state. These regional aquifers consist of deeper flow systems that in some cases are characterized by interbasinal movement of groundwater (Harrill and Prudic, 1998). Shallow karst flow systems generally are not present in these alpine areas because of low precipitation, and springs typically discharge upward through unconsolidated basin-fill deposits in the intervening valleys. Although some of the state's better known caves are developed in many of these mountain ranges, their origins are largely attributed to upwelling (hypogenic) thermal water mixing with shallow (meteoric) groundwater (Green, 2009), as evidenced by cave morphology and mineralogy, anomalously warm cave air temperatures, and warm springs that discharge in the vicinity of the caves. This paper provides an overview of alpine karst development in Utah, focusing on results of hydrogeologic investigations in karst areas that are characterized by active groundwater flow systems.

The Bear River Range

The Bear River Range is located in northern Utah and extends into southeastern Idaho (Figure 1). The range is bisected by the Logan River, which is the principal base-level stream into which groundwater discharges in the northern Utah part of the range. Karst features in this alpine region include large springs, losing streams in tributary drainages, caves and pits, sinkholes

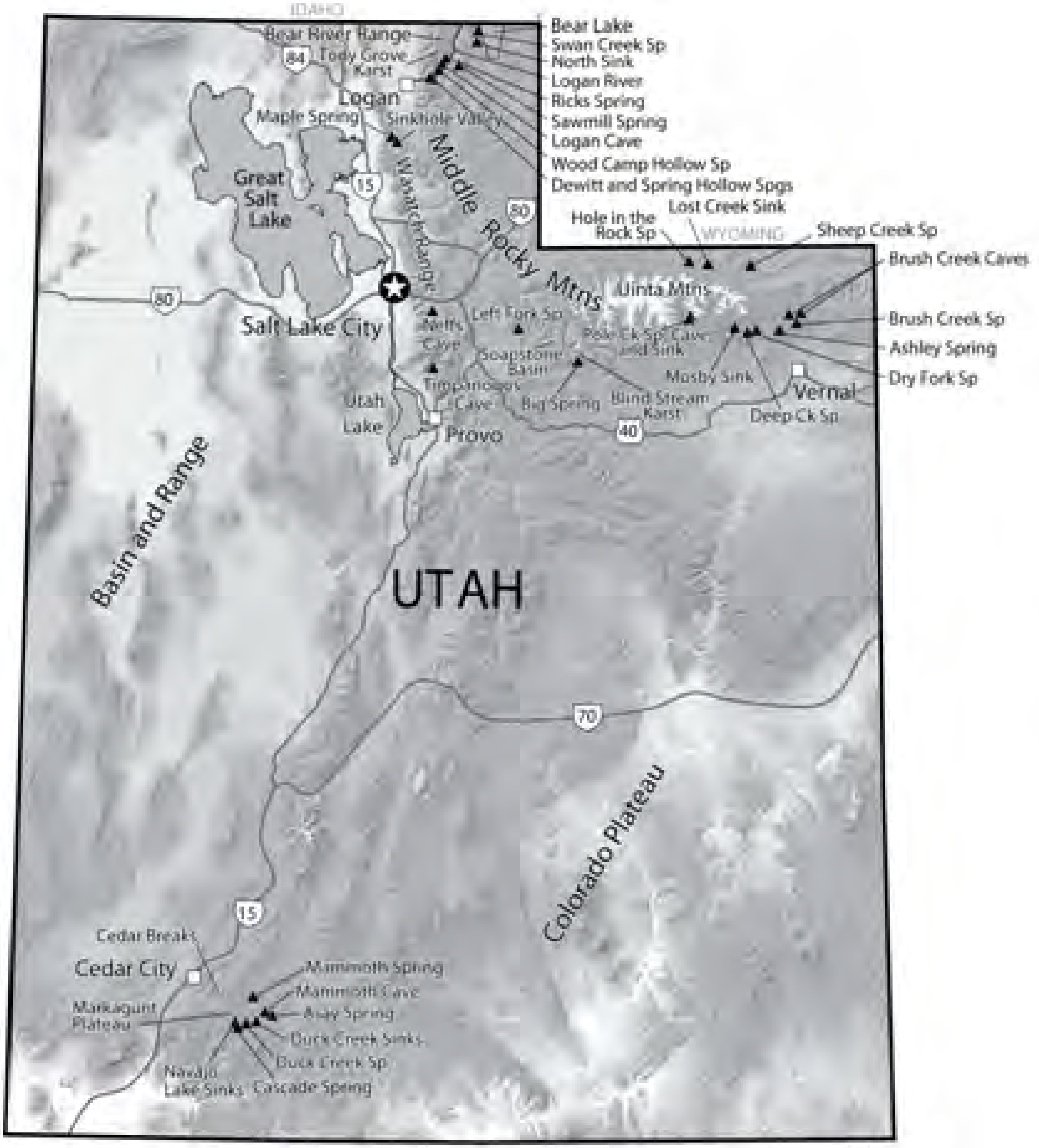

Figure 1. Location of selected karst springs and other karst features in alpine areas of Utah.

(dolines), and blind valleys. Glaciation occurred at altitudes generally above 2,500 meters (m) during the Pleistocene, resulting in the development of cirque basins where dissolution of carbonate rock was enhanced. Speleothem age-dating, glaciofluvial deposits in caves, and anomalous cave entrance locations indicate that cave development occurred primarily during interglacial periods, with significant modification of the landscape during periods of glaciation (Wilson, 1976).

The Bear River Range consists in large part of a thick sequence (as much as 1,500 m) of limestone and dolostone that ranges in age from Cambrian to Mississippian. North and west of the Logan River, the principal karst flow systems are developed primarily within the Ordovician-age Garden City Formation and Fish Haven Dolomite, the Silurian-age Laketown Dolomite, and the Devonian-age Water Canyon and Beirdneau Formations (Dover, 1987). Most of the known caves are developed in the Garden City Formation and Laketown Dolomite. The Swan Peak Quartzite appears to be a barrier to downward movement of water from the Fish Haven Dolomite to the Garden City Formation as well as influencing the direction of groundwater movement. All of the formations comprise the upper part of a large regional structure, the Logan Peak syncline, which plunges to the southwest at about 15 degrees. This syncline has a significant influence on groundwater movement and thus cave development, in this part of the range (Spangler, 2001).

Recharge to the karst aquifer takes place primarily by snowmelt runoff into sinkholes, closed basins, and pits in high-altitude glaciated (cirque) basins, as infiltration into the underlying carbonate rocks through fluvioglacial deposits in drainages, and as diffuse infiltration. More than 100 pits, caves, and sinks have been inventoried and explored in the Tony Grove (Figure 1) and adjacent White Pine karst basins, including Main Drain Cave, the state's deepest at 375 m. Precipitation falling in these areas moves vertically downward along solution-enlarged fractures (joints) and bedding planes to conduits that discharge groundwater to large karst springs. Although these concentrated inputs are significant, direct infiltration and movement along diffuse pathways probably is a more substantial component of recharge, contributing to long-term storage in the aquifer and supplying base flow of the springs year-round.

Discharge from the karst aquifer is primarily from second magnitude (0.28 to 2.8 cubic meters/second (m^3/s)) springs along the Logan River. Along the north side of the river in the Utah part of the range, these include from downstream to upstream, Dewitt, Wood Camp Hollow, Logan Cave, and Ricks Springs (Figure 1). Two other significant springs (Cascade and Logan River Springs), discharge along the upper reaches of the Logan River near the Utah-Idaho border. Only two significant springs (Spring Hollow and Sawmill) are known to discharge to the river from the south side (Figure 1). Discharge of individual springs is highly variable, with base flows of less than 0.03 m^3/s to peak flows of at least 2 m^3/s (Mundorff, 1971). Collectively, the springs provide a substantial component of streamflow in the Logan River, and during periods of base flow, Cascade and Logan River Springs provide nearly all of the flow in the upper reaches (headwaters) of the river. All of the springs respond primarily to snowmelt runoff, with peak discharge from late spring to early summer and base flow during the winter months.

On the basis of dye-tracer studies conducted since 1990 (Spangler, 2001), recharge areas for Dewitt, Wood Camp Hollow, and Ricks Springs are estimated to be between 20 and 50 square kilometers (km^2). Maximum (based on passive adsorption of dyes onto activated charcoal) groundwater travel times ranged from about one to less than four weeks, with sources of water originating from as much as 1,150 m higher than and 13 kilometers (km) from (linear distance) the springs. Results of these tests also indicate that groundwater basins for the springs in this region appear to be areally and stratigraphically separated, and surface-water drainage basins do not coincide with groundwater basins. The recharge area for Dewitt Spring, which supplies the city of Logan, largely coincides with the areal extent of the Logan Peak syncline. Although the spring discharges from Devonian carbonates, no significant caves are known from rocks of this age. Discharge from Wood Camp Hollow Spring includes flow from the Tony Grove and White Pine karst basins about 11 km north of the spring (Figure 1) and from some of the deepest caves (Main Drain and Nielsons) in the state. Cave development in these basins and groundwater movement to this spring appear to be confined entirely within the Laketown and Fish Haven dolomites. Both Logan Cave and Ricks Springs discharge from the Garden City Formation, a predominantly limestone unit. Logan Cave is the longest horizontal stream cave in this part of the range, with more than 1,300 m of passage developed on three levels. Ricks Spring discharges along a normal fault and receives part of its flow from the Logan River upstream of the spring. Groundwater from the Tony Grove Lake area also moves to the southeast to discharge at the spring. Exploration of the underwater cave behind Ricks Spring since its 2007 discovery has yielded 700 m of passage, including several air-filled rooms and a waterfall (Wendell Nope, oral commun., 2010).

Karst flow systems also are present in many other areas of the Bear River Range, particularly that part of the range which extends north into southeastern Idaho, as indicated by large karst springs, sinkholes, caves, and losing streams. However, little data are available for these areas. Results of dye-tracer studies in the 1980s (James Wilson, Weber State University, oral commun., 2006) showed that groundwater moves north from areas near the state line, rather than south toward the Logan River. Swan Creek Spring, the largest karst spring in Utah with a measured peak flow of about 9 m^3/s discharges from the eastern flank of the range into Bear Lake (Figure 1). Discharge from the spring may originate from large (1.5-km diameter) karst solution basins southwest of the spring, including North Sink (Figure 1). On the south side of the Logan River, results of preliminary studies indicate that discharge to Sawmill Spring (Figure 1) originates from a doline karst 3 km east of the spring. In addition, localized cave development occurs in the Tertiary-age Wasatch Formation; a marly, silty, conglomeratic limestone that mantles the Paleozoic-age carbonates in some areas of the Bear River Range.

The Uinta Mountains

The Uinta Mountains (Uintas) are a large east-west trending anticlinal structure (Figure 1), with a core that is composed of conglomeratic sandstone and shale of Precambrian age (Ritzma, 1959). Late Paleozoic-age carbonate and clastic rocks and Mesozoic-age clastic rocks unconformably overlie the Precambrian rocks along the flank of the uplift and generally dip about 10 to 20 degrees away from the core, except in areas of faults and folds, and on the north flank of the uplift, where they are considerably steeper. Superimposed on the Uinta Mountain Anticline are regional faults and fractures that have influenced the locations of the larger karst springs (Maxwell et al., 1971). Karst features are present in many areas of the Uintas where carbonate rocks are exposed at the surface. Sinkholes (dolines) and pits are more abundant in the southwestern part of the range, such as in the Soapstone basin area (Figure 1), where structural dip is lower and carbonate outcrop areas are more extensive. Losing or sinking streams can be found in many of the drainages, particularly where surface streams originating on the clastic core of the uplift cross the band of limestone that flanks the core. In the southeastern part of the range, Big Brush Creek and Little Brush Creek Caves, the longest stream caves in the state at 8 and 9.7 km, respectively, (Figure 1) were formed by capture and entrenchment of surface streams flowing off the core of the Uintas onto the limestone. As a result, excellent examples of blind valleys have formed at the entrances of both caves, and the largely abandoned valleys directly above the caves represent the original surface courses of the creeks. These caves are characterized by complex anastomosing networks that are continually being modified by snowmelt runoff. Cave development likely migrated down dip as the regional water table was progressively lowered by canyon cutting (Godfrey, 1985). Many of the caves in the Uintas were probably initiated or substantially enlarged during interglacial periods when excess runoff was available.

The principal karst flow systems and cave-forming units in the Uintas are developed in Mississippian-age dolomitic limestone and include the Madison and Deseret Limestones, and the Humbug Formation (Kinney, 1955). Average thickness of the carbonate units ranges from about 275 to 365 m. Results of dye-tracer tests have shown that groundwater flow directions in the southeastern part of the range are generally to the south and southeast, following the geologic structure. Direction of groundwater flow is influenced in large part by the structural dip of the rocks, regional fractures and faults, and localized breccia zones (Maxwell et al., 1971). Water typically flows down dip in the limestone to elevations as much as 640 m lower, where it discharges as large springs in the bottoms of the principal drainages that have dissected the flanks of the mountain range. Measured discharge of the larger springs has been as much as 5.7 m^3/s (Mundorff, 1971). In the southeastern part of the range, the Pennsylvanian-age Weber Sandstone overlies the Mississippian-age carbonates, and groundwater moving down dip in the limestone is generally confined beneath the sandstone (under artesian pressure). As a result, flow is typically upward from the limestone aquifer along fractures and faults in the overlying sandstone to discharge at the surface. In addition, lateral movement of groundwater between springs located in different surface-water basins has been shown to occur during periods of high discharge (Maxwell et al., 1971).

On the basis of dye-tracer tests carried out in the mid-1940s, mid-1950s, late-1960s, and in 1979, at least five major groundwater basins have been identified along the southeast flank of the Uintas. From west to east, these include Pole Creek, Deep Creek, Dry Fork, Ashley, and Brush Creek Springs (Figure 1). Detailed summaries of the hydrology of each of these basins can be found in Maxwell et al. (1971), Godfrey (1985), and Spangler (2005). Pole Creek Spring discharges from fluvioglacial deposits overlying the Madison Limestone and from nearby Pole Creek Cave, which serves as an overflow spring. This scalloped cave passage can be traversed for about 500 m before ending in a sump. Much of the flow discharging from this spring originates from Pole Creek Sink, a large blind valley 2 km northeast of the spring (Figure 1). Deep Creek Spring rises along the upthrown side of a northwest-trending fault that likely serves as a pathway for upward flow of water from the underlying limestone aquifer. Results of dye-tracer tests from Mosby Sink, 9.6 km northwest of the spring (Figure 1), indicated a groundwater travel time of about 14 days. Dry Fork Springs are intermittent and discharge from the Weber Sandstone upward through alluvium at several locations in Dry Fork (Figure 1). Flow lost through fluvioglacial deposits in the channel upstream of the springs enters conduits in the underlying limestone aquifer and moves upward along fractures in the overlying rocks to discharge at the surface. Water lost in Dry Fork and its tributaries also appears to move laterally (along strike) through the limestone aquifer east to Ashley Spring (Figure 1), where fractures in the overlying Weber Sandstone allow upward movement of water back to the surface. Brush Creek Spring also rises from the base of the Weber Sandstone where localized fracturing along the axis of an anticline has permitted upward movement of water from the limestone aquifer back to the surface. Results of dye-tracer tests during the summers of 1967 (Big Brush Creek) and 1968 (Little Brush Creek) indicate that much of the water discharging from the spring originates from both of these drainages via Big and Little Brush Creek Caves (Figure 1) (Maxwell et al., 1971).

On the northeast flank of the Uintas, the Mississippian limestone is very steeply (nearly vertical) dipping, and lateral movement of groundwater along bedrock strike has been documented by one of the longest traces in the western U.S. Groundwater travel time from Lost Creek Sink, a blind valley, to Sheep Creek Spring 26 km to the east, is within 2 weeks, as documented initially by Andrew Godfrey (U.S. Forest Service, oral commun., 2000) in 1979 and subsequently verified in 2001 by this author (Spangler, 2005). During the initial test, dye also was reportedly detected at Hole in the Rock Spring 8 km west of Lost Creek Sink (Figure 1), indicating an apparent bifurcation of the groundwater flow system beneath the ridge. Over the years, periodic digging in Lost Creek Sink has been unsuccessful in gaining access to the potentially longest cave in the state. The cave from which Sheep Creek Spring discharges can be accessed for only about 335 m before a sump is encountered.

Alpine karst flow systems also have been documented in the southwestern part of the range. Tracer tests conducted by Godfrey (1985) showed that discharge from Big Spring originates in part, from the Blind Stream karst area about 5 km northeast of the spring (Figure 1) at an altitude of about 3,200 m and also from the Log Hollow basin about 10.5 km east of the spring. In addition, tracer tests conducted by this author (unpublished data, 2005) have shown that discharge from Left Fork Spring (Figure 1) originates in large part from the Beaver Creek and Cedar Fork drainages northeast of the spring. Several significant caves are also located in this part of the range, including a deep, perennial ice cave.

The Wasatch Range

Mantua Valley is located about 26 km southwest of Logan, Utah, in the northern part of the Wasatch Range. Numerous springs discharge from Lower Paleozoic-age carbonate rocks along the perimeter of the valley, some of which are used for public water supply. Maple Spring (Figure 1) is the largest with a discharge that generally ranges between 0.14 and 0.23 m^3/s (Brigham City, written commun., 1995). The spring discharges from the Cambrian-age Bloomington Formation and serves as the water supply for a State fish hatchery. Sink Hole Valley (Figure 1), located about 4.8 km southeast of Maple Spring at an elevation about 425 m higher than Mantua Valley, is a polje-like feature that has likely formed as a result of both faulting and dissolution of the carbonate bedrock. Sinkholes along the margin of the valley provide an outlet for this closed basin, which is one of the largest in the state, with an area of about 4.6 km^2. Devil's Gate Valley, immediately southwest of Sink Hole Valley and site of a former reservoir, also drains internally through numerous sinkholes. Results of dye tracing to Maple Spring from Devil's Gate Valley indicated a groundwater travel time of about 5 days, or an average groundwater velocity of about 823 m/day (Rice and Spangler, 1999). Because the sink points are developed in the Ordovician-age Garden City Formation, groundwater flow from this area to the spring appears to cross major stratigraphic boundaries and northeast-trending faults, which do not appear to be barriers to movement of water between this area and the spring.

Neffs Cave is located just east of Salt Lake City on the western flank of the Wasatch Range, some 600 m above the base of the mountain (Figure 1). Discovered in 1949, the cave was surveyed to a record-setting depth of 355 m and was the deepest cave in the U.S. during the 1950s and 60s (Green and Halliday, 1958). The cave is currently the second deepest in Utah, and its great depth is attributed to development down the bedding plane of a steeply-dipping limestone along the contact with an underlying shaly unit. Secondary passages also are developed laterally along strike at a depth of 170 m. During the snowmelt runoff period, water enters the entrance of the cave and moves downward to its terminal end, where it presumably discharges to springs located near the base of the mountain front.

Timpanogos Cave (National Monument), located high on the south wall of American Fork Canyon about 48 km southeast of Salt Lake City (Figure 1), is well known for its magnificent display of helictites. During the snowmelt runoff period in late spring, water from unknown sources enters a pit in the cave near the exit point and moves downward into inaccessible passages. A tracer test by the National Park Service in conjunction with the Ozark Underground Laboratory in 1992 was unsuccessful in determining the discharge point of this water (Rodney Horrocks, written commun., 2009), which presumably is to unidentified springs along or in the American Fork River, about 400 m below the cave. Numerous small decorated caves are also located in other canyons in this part of the Wasatch Range.

The Markagunt Plateau

The Markagunt Plateau in southwestern Utah, east of Cedar City, lies at an altitude of about 2,750 to 3,050 m (Figure 1). Quaternary-age volcanic rock (basalt) caps large parts of the plateau and overlies the early Tertiary-age Claron Formation, a marly, sandy limestone and clastic unit that is locally cavernous. Exposures of this formation are spectacularly displayed at Cedar Breaks National Monument, which forms the western boundary of the plateau. On the Markagunt Plateau, dissolution of limestone beds within the Claron Formation has resulted in collapse/subsidence of the overlying basalt, producing a terrain that is characterized by ephemeral sinking streams and sinkholes as much as 300 m across and 30 m deep. Numerous large springs discharge from the Claron, and recharge to the aquifer that supplies these springs takes place by both concentrated (sinkholes) and diffuse infiltration through the basalt and into the underlying limestone where flow occurs along solution-enhanced fractures and bedding planes. Mammoth Spring (Figure 1), at an altitude of 2,500 m, is the second largest spring in Utah, with a discharge that ranges from less than 0.14 to over 8.5 m^3/s (Wilson and Thomas, 1964). The spring represents the principal discharge point for precipitation that infiltrates the sinkhole terrain on the plateau southwest of the spring. Dye-tracing studies by the U.S. Geological Survey have shown that a substantial amount of the water from Mammoth Spring originates from as far as 14.5 km southwest of and 580 m higher than the spring, with groundwater travel times of less than one week (Spangler, 2010).

Several significant (more than 300 m) limestone caves are present on the plateau, such as those from which Cascade Spring (Figure 1) and Arch Creek Spring (in Cedar Breaks) discharge. Developed along solution-enlarged joints, these caves are some of the longest known in the Claron Formation in the state. A number of lava tubes and other vulcanokarstic features also are present in the geologically young basalt flows that cover much of the plateau, including Mammoth Cave (Figure 1), with about 670 m of passage formed during two separate eruptions. Duck Creek lava tube, one of the longest lava tubes in the continental U.S. (3.35 km), contains a small stream year-round.

Located along the southern edge of the Markagunt Plateau, Navajo Lake is the largest lake in the state that is fed primarily by springs and is drained through sinkholes that apparently formed after the natural surface drainage was blocked by lava flows. Wilson and Thomas (1964) showed that water losing into sinkholes (Navajo Lake Sinks, Figure 1) in the lakebed below the dike across Navajo Lake discharges to the east at Duck Creek Spring in about 53 hours, then loses all flow again at Duck Creek Sinks, one of the largest insurgences in the state, and finally discharges at Asay Spring, 9.6 km to the east (Figure 1). Water losing into Navajo Lake Sinks also was shown to discharge to the south at Cascade Spring in 8.5 hours. Results of these studies indicate a bifurcation of the groundwater flow path that ultimately results in discharge to different surface-water drainage basins.

Summary

Karst systems in northern Utah are located primarily in alpine areas of the Uinta Mountains and Bear River and Wasatch Ranges. In these areas, active groundwater flow systems are developed in limestone and dolostone ranging in age from Cambrian to Mississippian. In the southeastern Uinta Mountains, surface water originating on the sandstone core of this anticlinal uplift sinks along the outcrop band of Mississippian limestone and moves down dip to large springs that discharge upward through fractured sandstone under confined conditions. Lateral movement of groundwater between adjacent surface-water basins in this area and along bedrock strike on the northern flank of the range also has been documented by dye-tracer studies, which include some of the longest traces (26 km) in the western United States. Karst features in the Uinta Mountains include some of the largest springs, best developed blind valleys, and longest stream caves in the state. In the Utah part of the Bear River Range, groundwater is recharged primarily by snowmelt runoff and discharges from large karst springs along the Logan River. The Logan Peak syncline has a significant influence on groundwater movement in this part of the range and delineated groundwater basins for the major springs appear to be areally and stratigraphically separated. On the basis of dye-tracer studies since 1990, recharge areas for the larger springs are estimated to be between 20 and 50 km^2, and groundwater travel times from as much as 1,150 m higher than and 13 km from the springs range from one to less than four weeks. Karst flow systems also are present in Tertiary-age limestone underlying basaltic volcanic rocks in the southwestern part of the state on the Markagunt Plateau. Dissolution of the Claron Formation and subsequent collapse of the overlying basalt have resulted in a terrain characterized by some of the largest sinkholes and springs in Utah.

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The Northern Karst Socio-Ecological Transect

Miriam Toro Rosario
Michigan State University
Center for Systems Integration and Sustainability
115 Manly Miles Building
1405 S. Harrison Rd.
East Lansing, MI 48823
tororosa@msu.edu
517-432-5238

Abstract

The Northern Karst Belt (NKB) covers 33% of Puerto Rico's geographic area and extends 160 kilometers between the municipalities of Loíza to Aguadilla. The diverse limestone formations in the area are characterized for their vast aquifers and underground cave systems supplying water to 25% percent of the population, 200 industries, and supporting 8% of the dairy production in the Island. Human demands of natural resources increase the pressure over the resources; especially now with the government of Puerto Rico proposing highway PR-22 cross a portion of the NKB. This project will extend along 46 kilometers of undeveloped lands, delicate community structures, and fragile ecosystems we depend on, i.e., 121 aquifers that supply water domestic and industrial use. Inspired by the work of the ecologist Michael Fay, a group of four Puerto Rican students organized an effort to walk the 46 kilometers segment of the proposed highway extension. Our main objectives were: (1) to document the potential impacts to economic activities and (2) to gather information of the natural and social resources to be impacted. The expedition members also collected audiovisual material documenting natural and social resources. Information collected is being used to produce a documentary film available online in order to inform citizens and policy-makers about the implications of this project. Our final goals are to educate the general public, generate public debate about the proposed road construction, and prepare reference documents easily available to any stakeholders.

Introduction

Puerto Rico is the smallest island of the Greater Antilles located between the Caribbean Sea and the Atlantic Ocean. As much as 27.5% of the Puerto Rico's surface is characterized by the presence of limestone, concentrated primarily in the Northern Karst Belt (NKB) but also extending to the southern karst and with some scattered patches across the island. The NKB lies between the central mountain range and the coastal plains and is characterized by its rough topography. Different social, ecological, and economic elements converge in the area with an extension of 142,544 hectares. Diversity present in the region can be described by the highest rate of tree species per area in the island, 220 species of birds, and the presence of habitat for 35 vulnerable or endangered species, including birds, reptiles, and plants.

The PR-22 highway is projected extended by a total of ten lanes along 46 kilometers within the island's northwestern municipalities of Hatillo, Camuy, Isabela, Moca, Quebradillas, and Aguadilla. Last year the Commonwealth of Puerto Rico proposed three options to reduce the travel time and traffic volume present in the road PR-2. The proponent agency, the Traffic and Transportation Authority, chose the construction of the PR-22 highway across a portion of the northwestern karst zone making their decision on information based upon a supposed projection to a population in the area and economic and time viability. In our opinion, the decision ignores technical and analytical data presented by the Natural Resources and Environmental Department in the Karst Study (2008) of karst areas with conservation priority and public policy previously established in the law §292, for the Protection and Conservation of the Physiographic Karst of Puerto Rico (1999). Facing these government irregularities to the environmental public policy, perceiving the lack of documentation on social and natural resources in the area, and understanding the irreversible impacts the project may cause, we four students decided to document the socio-ecological characteristics present in the area.

Northern Socio-Ecological Karst Transect

The Northern Socio-Ecological Karst Transect (NSEKT) consisted of an expedition of crossing the projected route of the PR-22 highway in the northwestern part of Puerto Rico by foot. Four graduate and undergraduate students composed the team: Waldemar Alcobas Santiago, Joel Mercado Molina, Mariana Rocas, and Miriam Toro Rosario representing the academic disciplines of geography, biology, communication, and environmental sciences, respectively. Our purpose was to document the ecological and social characteristics of the area and expand the available data offered by the government in the environmental impact assessment.

Previous to the expedition we: (1) familiarized ourselves with the environmental impact assessment of the project, contrasted that with published data of the ecological and social characteristics of the area, (2) obtained permits to cross private properties and conducted field visits, introducing ourselves to community members, (3) identified the topographic characteristics of the area, (4) georeferenced main points along the transect, and (5) printed aerial photographs.

Beginning in Hatillo and concluding in Aguadilla, the expedition was held from February 2nd to the 15th, 2011. Educational expertise determined the work division but eventually the work became more of a collective effort, especially during filming and interviewing.

Documentation of the ecological resources consisted of descriptive field notes, photographs, collection of GPS points, and video and audio recording of flora, fauna, and topography such as sinkholes, caves, rivers, wells or *mogotes.*

Data Collection

Social

During and previous to the expedition we contacted residents in each municipality the projected route would cross. Interaction with residents varied according to their receptiveness and time availability. We started with an introduction of ourselves, followed by a personal presentation of each member of the NSEKT project, and a brief summary of the PR-22. After this process, we requested interviews of citizens where we collected their reactions and comments to the highway in an audio or video interview.

Diverse findings were constantly present, ranging from people totally unaware of the highway proposal to community leaders organizing their members against the threats of expropriation. Many citizens and landowners were unaware of potential expropriations sometimes causing relocation of nuclear families living in the same community. Data collected in interviews showed support of infrastructures that many families and neighbors depend upon to subsist in the daily life dynamic, i.e., single mothers leaving their children with a grandmother or relatives during working hours.

The most striking economic impact will be to land and cattle owners associated with milk production on the island; usually concentrated in Hatillo municipality. The dairy industry is composed by 25 farms, which may be adversely impacted by severe fragmentation of land. The isolation of terrain could adversely impact the mobility of the cattle and could subsequently reduce the actual milk production of 40,000 liters of milk from each farm.

Some other impacts to the economic sector can be to the 130,000 jobs generated directly or indirectly in the area by pharmaceutical industries. Regional impacts of the highway can affect the economy in the entire island, reducing the $30 billion exportations (2003).

In addition, cultural and historical hotspots were identified and recorded; some of these are Palacete Monroe, irrigation channels from Isabela to Aguadilla, hydroelectric infrastructure, antique agriculture terraces, and local handcraft workshops.

Ecological

Data was collected using field notes, video, and audio recording. We documented the main biological and habitat characteristics of the flora and fauna sighted during the 13-day expedition. Bird counting and vegetation census was conducted mostly in forested patches.

Also, we paid special attention to filming ecosystems responsible to maintain and supply our domestic and industrial water demand such as *mogotes*, aquifers, rivers plains, caves, sinkholes, pastures, and forest areas.

Due to limits of time and filming material, video and audio was generally recorded in the presence of fauna, flora, and scenic views.

Conclusion

Data collection and expansion is imperative to understand and deal with decision-making processes involving potential impacts to complex social and ecological systems. Decisions based upon scarce or biased sources of information may lead to irreversible damages to sensitive ecological and social features. Some examples are the potential threats to the functionality in aquifers that supply water for human consumption and pharmaceutical industries as well as disruption of support webs created and maintained by members of the same community. Without the proper public consulting process required by law, all these factors are perceived and ignored by government officials and decision makers.

In conclusion, we conducted 22 interviews, produced 3,500 photographs, and 17 hours of filming material. Our intention with the NSEKT is to edit this audiovisual material and summarize all main findings of the expedition in a short film. The documentary will be broadly available online and presented to the community members living along the proposed highway as well as to government officials responsible for the decision making process of the PR-22. In addition, we intend to produce a document with comments and recommendations incorporating our ecological findings that contrast the environmental impact assessment made by the Traffic and Transportation Authority. As a final goal, we want to generate public debate within the general public and the scientific and political spheres in Puerto Rico, as well as abroad, concerning the benefits and impacts of the planned highway across the northwestern karst zone.

Kids and Caves: Explore the Potential

Karissa DeCarlo
Supervisory Interpreter
Timpanogos Cave National Monument
karissa_decarlo@nps.gov

BJ Cluff
Timpanogos Cave National Monument
bj_cluff@nps.gov
801-756-5239

Poster Only

Over 2.2 million people live within an hour drive of Timpanogos Cave National Monument. Typically 37% percent of our visitation is age 15 or younger. Due to our location and our visitation, Timpanogos Cave is able to reach numerous children through interpretive cave tours and outreach programs. The future of cave and karst preservation will depend on building an ethic of stewardship in the next generation. Join us for a conversation on reaching out, inviting in and considering how to best leverage our unique position to encourage the value of all cave and karst resources.

Incorporating Karst/Cave Science in Cave Guide Training

Patricia Kambesis, Leslie North, Chris Groves, Jason Polk
Hoffman Environmental Research Institute
Western Kentucky University
Bowling Green, KY 42101

Abstract

Cave guide training for commercial cave tours typically consists of familiarization with the cave route and associated infrastructure, tour protocol as established by the owners/mangers, basic tour group management, competence in use of basic cave equipment, safety and emergency protocols, and often times cave conservation. This assures that the guide conducts a tour responsibly with respect to the visitor and the cave. Most show caves have an interpretive facet to their tours. To that end, the guide may be provided with an interpretative outline or script that details descriptive and sometimes scientific information about natural resources within and specific to the show cave. It is not uncommon for the guide to convey interpretative information to the visitor either recited rote or presented as summarized from the script. These modes of interpretation for visitors do not provide a quality educational experience, do not instill an appreciation for caves in general, nor do they motivate visitors to protect caves and karst resources. What makes a cave tour an effective learning experience for visitors is how the guide presents their knowledge about the cave and karst in general. A background in cave and karst science, and how the information relates to the specific show cave and area, gives guides a better understanding of caves and karst that they can then convey to visitors on their tours. The authors provide examples from science-based cave guide workshops that have been conducted in Barbados, Puerto Rico, and in China that have expanded the knowledge of the cave guides and provided them with interpretative resources to help them enhance their tours. Examples of training methods and effectiveness of the training will be reviewed.

Introduction

Commercial cave managers typically provide training for their guides that include familiarization with the cave route and associated infrastructure, tour protocol as established by the owners/mangers, basic tour group management, safety and emergency protocols, and some cave conservation. For guides working wild tours, training in standard cave techniques and use of basic cave equipment is also provided. This assures the guide will conduct a tour responsibly with respect to the visitor and the cave.

Most commercial caves have an interpretive facet to their tours and that information is provided to the guide via an interpretative outline or script detailing descriptive and general scientific information about natural resources within and specific to the show cave. It is not uncommon for the guide to convey interpretative information to the visitor either recited rote, or presented as summarized from the script. Some commercial cave managers have determined that these modes of interpretation do not provide a quality educational experience for the visitor, do not instill an appreciation for caves in general, nor do they motivate visitors to protect caves and karst resources.

In our experience, what makes a cave tour an effective learning experience for visitors is in how the guide presents their knowledge about the cave and karst, in general. A basic background in cave and karst science, and how the information relates to the specific show cave and area, gives the guide a better understanding of caves and karst, that they can then conveon to visitors on their tours. This paper outlines the methods we have used in science-oriented cave guide workshops that have been conducted in Barbados, Puerto Rico, and in China. The feedback we have received, both from management and from guides, is that the topics we covered in our training workshops have expanded the knowledge of the cave guides and provided them with interpretative resources to help them enhance their tours.

Training Preparation

The purpose of the cave-karst science part of guide training that we have conducted is to give the guides a basic background in current cave and karst science and to relate that science to *their* specific cave. The latter is very important, as the same processes do not form all caves; a point we try to convey to the guides. We also emphasize that caves are not just a collection of speleothems – but rather are unique ecosystems that can also serve as "time capsules", preserving evidence of past natural processes (such as climate change) and human activity. An overview on White Nose Syndrome is also incorporated into the science training.

For general cave guide training, we meet with management before conducting the actual workshop to discuss requirements for the cave tour (standard tour and wild tour, if applicable), guide responsibilities, liability issues, and rescue protocols. In order to tailor the science training to the specific cave, if there is a visitor or interpretive center, we make a site visit and also participate in an actual cave tour or tours to get an idea of the information the visitors are being provided and to scope out features of interest to suggest to the guides. If possible, a review is done of existing interpretive materials.

Before instruction begins, the guides are given an initial survey (Figure 1) to determine their state of knowledge about caves and karst, and to ask them what additional information they would like to know. After the training, the guides are given the same survey but with some additional questions. Post training, the exit survey results inform us whether the training was effective and help us answer specific questions the guides may have.

Training Content and Format

We cover a range of topics that are modified to suit the specific cave the guides will be interpreting. Figure 2 is an example of a syllabus we used for two-day cave guide training conducted in Barbados, Puerto Rico, Malaysia, and China. Topics cover basic cave and karst science, review of general concepts, and specific examples that are pertinent to the show cave. A brief overview on different types of cave development is reviewed (with examples for each) and then a more detailed explanation of cave development of the show cave the guides will interpret. An overview on cave ecology is presented with examples of typical and local cave fauna and flora. An overview of White Nose Syndrome, as it is developing in the United States is reviewed along with results of the most recent research and current protocols for decontamination. We provide a review of historical, cultural, and archeological significance of caves and, if applicable, to the local caves. These topics segue into current human use, and impact and then into science and how it applies to cave conservation. Methods for the study of caves and karst are outlined and the significance of caves are reviewed. Final presentation is a photo review and interpretation of features and resources specific to the cave that guides will be interpreting.

Workshop format is part lecture and part hands-on. Specifically, three hours in the morning are spent covering syllabus topics via PowerPoint lecture and discussion. Afternoon sessions are conducted in-cave to relate lecture materials to cave features, and to point out and discuss features of interest. The guides are then tasked with creating their own interpretive talk about some aspect of the cave that they then present to us.

For their reference, copies of our lectures and more detailed course material are provided to management and to the guides. In addition, we also compile a set of online-links with additional details and information about topics that were covered during the training. The goal is to make available to the guides reference materials and additional opportunities for pursuing knowledge of specific topics and areas.

Summary

The results from post training surveys and from the assigned in-cave interpretive talks the guides were assigned indicated that the guides did come away from the training sessions with a better understanding of caves and karst and also with more insight into the processes that formed the caves within which they worked.

Instituting a module on cave and karst science into overall cave guide training broadens the cave guide’s basic understanding of cave and karst processes and features, and gives them the knowledge and confidence to conduct more interesting and effective cave tours.

Figure 1:

Pre and Post Cave Guide Survey

If you don't know the answer or have an educated guess to a question you may leave it blank.

1) Please define the word *karst* or describe a *karst landscape*. ______________________________

2) How is *karst* formed? ______________________________

3) How are *caves* formed? ______________________________

4) Generally speaking, please indicate whether the following statements are true, false, or you don't know.

	True	False	Don't Know
a) Limestone rock acts as a good filter for water.			
b) Water can rapidly travel from the surface to subsurface in karst areas.			
c) Less than 10% of *worldwide* freshwater drinking supplies come from karst aquifers.			
d) Caves can serve as a pathway for water to travel through karst terrains.			
e) Water in you cave only comes from directly above the cave.			
f) Bats are blind.			

5) Please describe how humans may directly impact karst landscapes through the following practices:

a. Growing crops or raising livestock ______________________________

b. Land clearing ______________________________

c. Dumping trash or polluted water in sinkholes or gullies ______________________________

6) How do stalagmites form? ____

____

____

____

7) Are there any differences between animals that live above ground and those that live below ground? If so, what are they? ____

____

____

8) Where does the water in your cave come from? ____

____

____

9) What are some of the potential risks of guiding people through a cave?

____

____

____

Post workshop additional questions:

10) Please describe what you feel you learned about during this training period. ____________________

____

11) Do you prefer being a front guide, back guide, or no preference? Why? __________________________

____

12) What resources do you think you still need to become a great tour guide (specific material, specific training, etc.) ____

____

____

Figure 2:

Guide Training Syllabus (used for Harrison's Cave, Barbados)

Tentative Guide Training and Tour Assessment Schedule

Hoffman Environmental Research Institute

I. Meet management team to discuss requirements for the cave tour, guide responsibilities, liability issues, rescue protocols:

- See Visitor Center facility
- Take standard tour of cave
- See proposed wild cave tour
- Review of existing interpretative materials

Guide Training cave tour – cave techniques, safety, conservation:

- Evaluation of guide overall knowledge on caves and caving
- Overview on caving techniques
- Equipment review
- Safe caving techniques
- Rescue protocols & communications
- Cave conservation
- Review of guide responsibilities
  - Time permitting – underground orientation

Guide Training – cave science overview for interpretation

- How caves form
- Basic cave geology
- Biologic systems
- White Nose Syndrom overview
- Historical information
- Human use of caves
- How we study and understand caves
- Overview for wild cave tour

Interpretive Training of proposed wild tour (in cave)

- Hands-on learning for guides

Wrap-up meeting and recommendations

- Exit survey – Post workshop evaluation of guide overall knowledge on caves and caving

The Role Interpretation Plays with Cave Resource Protection

Dawn Ryan
Interpretive Ranger
Sequoia National Park
dawn_ryan@nps.gov

The mission of the National Park Service states in part, "..to preserve and protect and leave unimpaired …. for the enjoyment of future generations." National Parks serve two primary purposes; they preserve recognized significant features, while at the same time allowing for their enjoyment. And though it may seem contradictory that preservation and enjoyment are mutually incompatible, to believe such is to misunderstand our parks. For the modern history of our parks is the story of the relationship between both goals. As natural resources managers most of us are involved in the "preserve and protect" aspect of the goal. However, parks are not just zones of preservation and they are not merely areas set aside to be enjoyed. Successful park management lies in the combination of these two goals and this is where the role of the interpreter and volunteer come in to play.

As resource managers you may be involved in reading public comment. However, as an interpretive ranger I have the opportunity to read comments and listen to park visitors first-hand regarding their experiences in the parks. Below are some comments from visitors who, after visiting Sequoia National Park and Crystal Cave, have taken the time to write about their positive experiences.

"I will never think of caves, water and bats the same way again."
"After listening to the program I've removed the lawn in my yard and
replaced it with native plants."
"The cave program really opened my eyes on just how important water is."

Comments made with reference to Rangers in the Classroom:

"Thanks for coming to my school. I used to be afraid of bats, now I love bats."
"Me and my dad made a bat box that we put up on our garage. Thanks for
coming to our school."

Figure 1 is from a 7-year-old park visitor named Aaron. Aaron and his mother spent a week at Sequoia and Kings Canyon National park. They attended several programs including my campfire program on caves. Aaron even finished his Junior Ranger program and earned his badge. At the end of their stay Aaron and his mom stopped into the visitor center and presented me with the picture in Figure 1. If you look at it closely you can see the giant sequoias and below them is Crystal Cave with its spider web gate and the prominent dome formation found in the Dome Room of the cave.

Figure 1

My career in the National Park Service began with an inspirational trip into a commercial cave. My reason for sharing these examples is that although all commercial cave experiences may not be as life changing as mine was, you have an opportunity to reach many people in different ways and to connect them to your resource: the cave.

What is Interpretation?

Figure 2

The mission statement of the National Park Service states in part, "To preserve and protect and leave unimpaired for the enjoyment of future generations." National Parks serve two primary purposes: they preserve recognized features of special significance while at the same time allowing for their nondestructive enjoyment. It has often been said that these two objectives are contradictory – that preservation and enjoyment are mutually incompatible. But to believe such is to misunderstand our parks, for the modern history of our parks is the story of the relationship between these two goals. As natural resources managers, most of us are involved in the preservation and protection aspect. However, parks are not just zones of preservation. Nor are they merely areas sat aside for enjoyment. Successful management lies in the combination of these two goals, and this is where the role of the interpreter and volunteer comes into play.

To understand interpretation, let me begin with its origins. As more and more national parks were established in the early 1920's the new director of the park service, Stephen Mather, saw it as a goal for the parks to create a base in educating the public and, in turn, creating public enthusiasm for this new idea of national parks. To support and encourage these park programs, Director Mather made Ansel Hall the chief naturalist of the National Park Service in 1923. Organizationally, Hall became chief of the Service's Education Division, headquartered at the University of California at Berkeley. At the Eighth National Park Conference, held at Mesa Verde in October 1925, Mather voiced strong support for interpretation and made the Education Division one of three equal units in the Service organization, along with Landscape Architecture and Engineering. The functions of the Education Division included overseeing and setting standards for the hiring of park naturalists. In 1926 Hall prepared an information sheet and application to send the numerous aspirants for naturalist positions. The information sheet stressed the difficult requirements of the job. In a communication to Horace Albright, Hall wrote the following:

> *" The duties of Ranger Naturalist require a full day's work each day - work entailing continual contact with the public. If you are not absolutely certain that you can maintain an attitude of enthusiasm and courtesy, please do not apply for work of this sort ...."*
>
> *"A Ranger Naturalist may have to talk to 1500 to 2000 persons; his lectures may be a part of a general entertainment program where his competitors will be Jazz music, comedy skits, or other such forms of amusement...."*
>
> *"This should automatically weed out fully 95% of the unfit applicants, most of whom are absolutely ignorant of the duties of the ranger naturalist sand are merely looking for a pleasant vacation in one of the parks."*

But, as time went on, things began to change the *lectures* changed to *interpretation*. We probably could all have some very interesting conversations about hypogene speleogenesis or heterotropic microorganisms as factors in substrate selection of troglobitic invertebrates. But to the average person that means nothing. And while scientists arrange information in a way that explains how nature works, and historians similarly research the past and sort and arrange evidence in order to understand the relationships of people and events, a good interpretive program articulates a reason or reasons for caring about a resource. Freeman Tilden, considered the father of interpretation, said, "Information, as such, is not interpretation. Interpretation is revelation based upon information. The chief aim of interpretation is not instruction

Figure 3

but provocation. Interpretation is an art which combines many arts, whether the materials presented are scientific, historical, or architectural. Any art is in some degree teachable." Think of the resource as an appetizing pie. The interpretive program takes some of the most captivating characteristics, shapes it into that pie and the audience is given a slice of significance. When the interpreter gives the audience only a slice, they will always want more. So how does the interpreter do that? By using interpretive tools. Interpretive tools involve selecting ways to actively and/or passively involve the audience.

Formal Interpretation

Formal interpretation actively involves a visitor. The cave is the most effective tool for the interpreter. By bringing the public into the cave, the visitor can see the water flowing and they can see the bats and other animals. They can hear the human stories. One of the stories I enjoyed reciting when I worked at Crystal Cave was how the CCC worked all winter in Sequoia National Park to develop Crystal Cave. There have been many visitors who have relatives who worked for the CCC during the depression and can relate to this story. Visitors can also see first hand human impacts and vandalism. Unfortunately, Crystal Cave suffered vandalism in 2006. Interpretation is not necessarily expected to make visitors feel good but is expected to provoke. This creates a connection and, as a result, visitors reach their own conclusions.

Not every visitor is able or willing to go into a cave. How are those people reached? By bringing the cave to the people. Programs such as Rangers in the Classroom bring rangers and the cave to the local schools. One of the best ways to reach adults is through their children. Critter Talks or other programs outside the cave, near the visitor center, and evening campfire programs can reach thousands of people in a single summer. Through these talks, the interpreter brings the cave alive by showing photos and having bones and other examples of the cave, which allows people to see and touch even though they cannot get into the cave.

Information Interpretation

Informal interpretation gives the visitor a way to read and absorb knowledge at his or her own pace. Well-placed and well-worded waysides and exhibits are viewed by millions and can make a significant impact. Other sources of informal interpretation are through your Public Affairs person, park newspapers and websites. These are invaluable tools if used properly. An extremely large number of people plan their vacations based upon information found on the web.

Why Should the Resource Manager Get Involved in Interpretation?

The role of the interpreter is to make important information available and relevant to the public. You, the resource managers, make that important information available. If you want the public to recognize and accept that what you are doing is necessary rather than having the public see you as an intrusive government policy, that goal can be reached via the interpreter. You cannot succeed in resource protection without broad public support. Figure 4 shows the annual visitation numbers for all the parks I could think of that have caves.

As you can see, the total number of visitors is in the many-millions. This is the number of people you have the opportunity to connect with. Woven into these numbers is the interpretive opportunity. For management will not succeed in protecting caves unless the public understands the value of caves. Consider the most stable structure - the tripod. At the top there is the resource manager and the work we all do, i.e., surveys, inventories, research, restoration, etc. Over to one corner is Law Enforcement. And while Law Enforcement is very important in many aspects of cave resource protection, you can only write so many tickets. You get more bees with honey. But without education and without interpretation, the other two jobs are very difficult to accomplish. You have to convince the public to support cave protection.

The last tool that is important to resource managers are your volunteers. With budget cuts, the issue of WNS, and groups like the CBD pressuring for cave closures, I realize it currently is a tough time for resource managers. But your volunteer base plays a very important role in helping to spread the word about the significance of caves. These cavers are volunteers who talk to thousands upon thousands of people. They are your eyes and ears in remote areas that cannot be visited on a regular basis because of budget and staffing cuts. They do the work that budgets can no longer pay for, i.e., gating, surveys and restoration. One big volunteer base to work with is the Cave Research Foundation. These cavers have volunteered nearly 100,000 hours since 2005 at Mammoth Cave alone. What have they done or what can they do for you in your park? When you close the caves down, when the public is excluded from public lands, the educated public becomes the uninformed public. It creates the barrier *biology* versus *humanity*. The public perception regarding caves is changing; many no longer think of caves as muddy holes infested with flying rodents. Let us not lose the ground already gained.

I want to encourage you as resource managers to take the time necessary to train your interpretive staff and particularly to involve them and your volunteers in your projects. Consider these folks as willing and eager members of your staff. You, and most importantly the resource, will reap the benefits in the long run.

- Apostle Islands 5, 121, 389
- Carlsbad 41,289,278
- Great Basin 3,123,085
- Jewel Cave 5,460,481
- Kings Canyon 49,674,944
- Lava Beds 6,084,524
- Mammoth 81,588,286
- Oregon Caves 7,416,547
- Pinnacles 9,018,873
- Russell Cave 1,197,320
- Sequoia 56,443,491
- Timpanogos Cave 7,688,724
- Wind Cave 37,674,950

Figure 4

Bats at the Boy Scout Jamboree An Outreach Event for Bat Education

Carol Zokaites
National Coordinator of Project Underground and
Environmental Education Manager for the
Virginia Department of Conservation and Recreation
czokaite@vt.edu
540-382-5437

Abstract

"What does a Bat Biologist do?" "What is bat guano used for?" "What is White Nose Syndrome?" These were just some of the questions Scouts discovered the answers to at the Boy Scout Jamboree. Scout troops around the country had been asked to stop visiting caves because of WNS management strategies. We decided telling the Scouts and their leaders about bats and WNS would answer some of their questions as to why the caving trips had stopped.

The 2010 Boy Scout Jamboree, at Fort A.P. Hill near Fredericksburg, Virginia, marked the 100th anniversary of the Boy Scouts of America. The national event was attended by 45,000 Scouts from across the United States. The Virginia Department of Conservation and Recreation (DCR) sponsored an exhibit area at the Jamboree on Bats and White Nose Syndrome (WNS). Project Underground, Bat Conservation International (BCI) and the Virginia Tech Science Outreach Program where partners in this project.

The exhibit contained three stations, each one with a different bat subject. Each station had an educational display with pictures and problems or activities for the Scouts to solve. The Scouts asked great questions and were very interested in WNS and the problems the syndrome caused the bats. They seemed to understand the importance of bats to the environment and the need to protect the bat habitats. 13,000 Scouts visited the Bat exhibit during the nine days of the Jamboree. The Scouts increased their knowledge about bats and came away with a more positive attitude towards them.

Representing, Classifying, and Monitoring In-Cave Features with GIS; Methods Used by the Bigfork High School Cave Club of Northwest Montana

Sandi Baker, Ernie Cottle, Katie Lafeaver, Brennen Shaw (participating club members)
and Hans Bodenhamer (teacher/club sponsor)
Bigfork High School Cave Club
PO188, 600 Commerce Street
Bigfork, Montana, 59911

Sponsor contact:
hansb@bigfork.k12.mt.us (406) 837-7420
hbode@centurytel.net (406) 257-7827 (summer)

Abstract

The Bigfork High School Cave Club has completed numerous cave conservation and monitoring projects in partnership with federal land managers. Club members have received considerable recognition for their work, including the 2009 President's Environmental Youth Award. The club typically established three types of in-cave monitoring: (1) temperature and humidity measurements, (2) photo monitoring, and (3) visitor impact point and area monitoring (VIP and VIA). The club represents and analyzes their monitoring using Geographic Information Systems (GIS). Inputting monitoring into GIS begins with georeferencing cave maps onto a base layer. Next, monitoring points are drawn relative to features represented on the georeferenced cave map using the pencil tool in editor. For each point a description and feature classes are included in the attribute table. Feature classes have been developed for feature type, significance, fragility, and condition. GIS facilitates organization of the club's copious monitoring data. Examples of how the club uses GIS to represent and analyze data include graphical representation of resource conditions, evaluation of the extent and distribution of feature types, calculating and comparing areas of polygons that represent expansive features, and deriving statistics for classified features. The club has developed a procedure that links monitoring to management. The procedure involves: (1) assigning a LAC management class to each feature, (2) setting a LAC threshold for each class of feature and having managers commit to a predetermined management action should the threshold be exceeded, and (3) implementing predetermined management.

Background

The Bigfork High School Cave Club of northwest Montana was created in 2005 to provide high school students with opportunities to participate in wholesome recreational activities and conduct cave conservation projects through partnerships with local land managing agencies such as the US Forest Service and National Park Service. The club maintains an active membership of about 15 students. Each school-year club members participate in at least three recreational trips and three conservation projects. Conservation projects include removing graffiti and trash from heavily vandalized caves, mapping passage, and inventory and monitoring of sensitive cave resources using Geographic Information Systems (GIS).

In 2010, the club was awarded the President's Environmental Youth Award (PEYA) for their work in the conservation of caves in Glacier National Park (Bodenhamer, 2010a). They were only one of ten groups in the nation to receive the award and as part of the award ceremony two club members were flown to Washington DC to present their project to the director of the EPA and meet President Obama. In 2010 they were also invited to present at the opening ceremony of the International GIS Users Conference in San Diego (Bodenhamer, 2010b). At the conference they spoke to a gathering of over 10,000 people!

In 2011 the club finished an aquatic invertebrate study for Glacier National Park (see Cottle, within these proceedings) and worked in caves on the Flathead National Forest to establish monitoring of mineral resources, macroscopic biology, bat sign and bat hibernacula. The club's bat work is being done in coordination with Montana Fish, Wildlife, and Parks in preparation for the potential spread of White Nose Syndrome to Montana. Also in 2011, the club completed monitoring for 11 caves in Grand Canyon National Park (Baker et al. 2011). This work was completed in one week of field work followed by two months of GIS input and report preparation.

At the 2011 National Cave Management Symposium in Midway, Utah the club presented highlights of the work in Glacier and Grand Canyon National Park. During questions and answers, there was much interest in methods the club uses to represent, classify and monitor in-cave features with GIS. This article overviews these methods. Those interested in learning more about the club's monitoring, GIS use, or other aspects of their work are encouraged to contact the club sponsor.

Monitoring Methods

Club members typically conduct three types of in-cave monitoring: (1) temperature and humidity measurement, (2) photo monitoring, and (3) visitor impact monitoring.

Temperature and Humidity

Temperature and humidity are measured using an Extech model HD500 psychrometer with IR thermometer. Temperatures are measured at the ceiling, floor, and mid passage (or chest height for high-ceiling passage), and relative humidity is measured at mid passage (or chest height). The location of measurements is marked on a 1:240, paper copy of the plan map of the cave. Typically the measurements are made at 50 foot intervals throughout the cave. The club has also used dataloggers to record temperature fluctuations within caves, but because fluctuations in most caves are minimal, we feel the measurements taken with the Extech are more than adequate to detect climatic or human caused changes to temperature and humidity within most caves.

Photo Monitoring

Photo monitoring is established using a handheld, digital camera with greater than 10 mega pixels and camera-mounted flash. The point from which the photo is taken is marked on a 1:240, paper copy of the cave map, and a brief description of the feature and the magnetic azimuth of the photo view is recorded while in the cave. Magnetic azimuths are taken with a Suunto KB-20 360R compass.

Club members have repeated photos taken by previous club members from earlier years and also repeated archived, historic photos taken from as long ago as 1912. Before in-cave work, club members digitally label cave name and photo number on each photo to be repeated. This facilitates managing the photos if they are dropped or shuffled in the cave. Each photo is then printed (usually in black and white) on 8.5 by 11" paper and laminated. The 8.5 by 11" format makes the prints easy to view in the cave and the lamination protects the prints from the cave environment and rough handling. Club members relocate photo points within the cave, view directions using map points and recorded azimuths, and mimic framing by holding the laminated prints beside the camera and until the views are similar.

Although better quality photos could be taken with a higher quality camera, and more precise framing of views could be achieved using a tripod set to a measured height above a point marked in the cave, the beauty of the cave club's method is it is quick and relatively easy to establish and repeat. This allows club members to establish many more photo points than they would if they needed to set up a tripod, measure camera heights, and manage a more expensive camera and an off-camera flash. It also makes it easy to add additional points during repeat monitoring trips. The club's results using this "quick and inexpensive" method are impressive. The method requires careful study of repeat and original photos to detect changes in views that are "slightly off", but sitting in front of a computer comparing cave photos is less challenging than hauling extra gear and fine tuning view directions while in a cave. An example of a repeated and an original photo with slightly off views is presented in Figure 1.

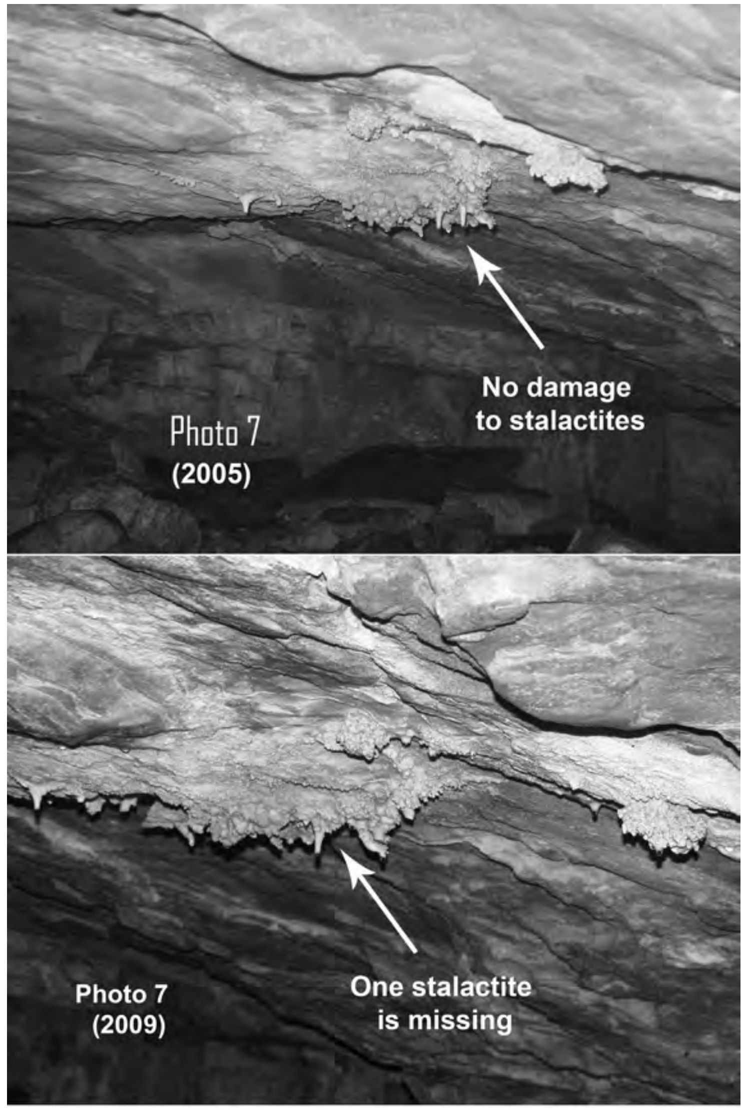


Figure 1. An Example of a slightly off photo view used by the club to detect changes to mineral features

Visitor Impact Point and Visitor Impact Area Monitoring

Visitor Impact Point (VIP) and Visitor Impact Area (VIA) monitoring are established using simple procedures described in the 2006 edition of Cave Conservation and Restoration (Bodenhamer, 2006). In overview, these procedures involve locating, describing, and classifying human-caused changes to cave features by marking points (VIP) or drawing areas (VIA) on a detailed map of the cave. The club classifies impacts to cave features using the scheme described in Cave Conservation and Restoration, but has added classification schemes for the fragility, significance, and management of cave features. Classification schemes are described later in this article.

The club has experimented with using ArcPad on handheld Trimble Junos for in-cave collection of visitor impact and other types of monitoring data. We have loaded cave maps and drop-down menus into the Junos. This allows us to digitally draw points, polygons, and transcribe descriptions while in

Figure 2. Cave club members using a Juno

the cave that can be directly uploaded into GIS following the monitoring trip. This greatly reduces the amount of time it takes to enter data into GIS. However, the Junos with ArcPad are expensive, about $900, which makes them challenging to acquire and worrisome to transport and use in a wet, rugged cave environment. Furthermore, the Junos seem to work well for collection of point data, but because the small screen it is difficult to draw polygons. A photo of club members recording monitoring data with a Juno is presented in Figure 2.

Representing Data in GIS Layers

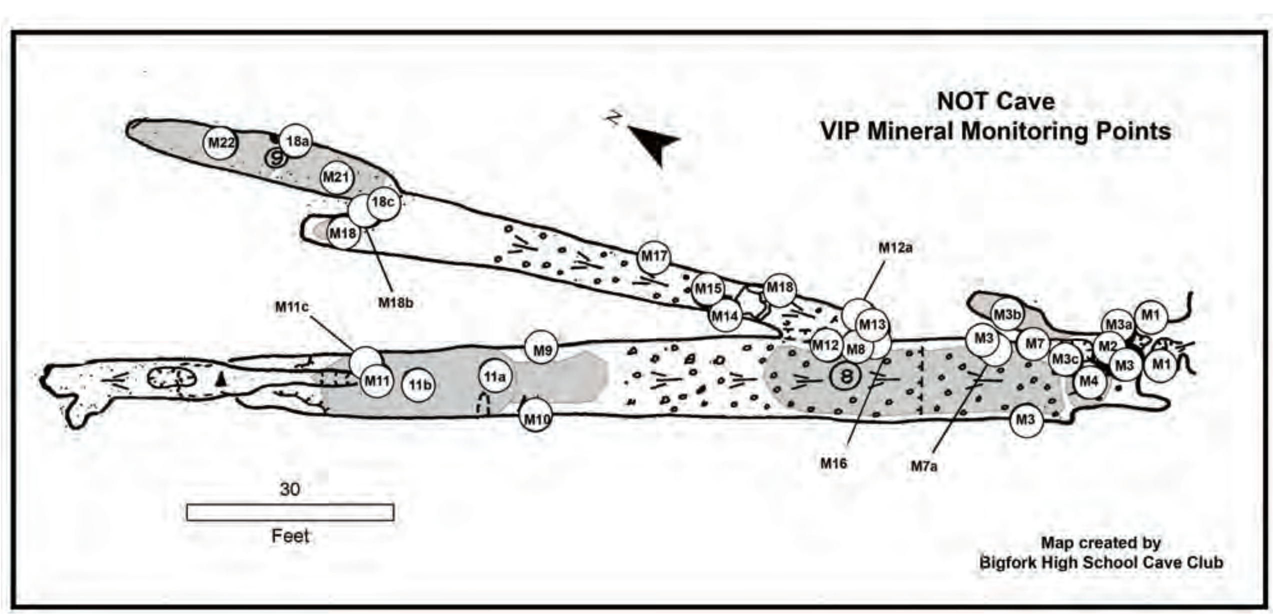
Detailed cave maps are essential to establishing in-cave monitoring using methods practiced by the Bigfork High School Cave Club. Preferably, maps are at a scale of 1:240 with most features larger than 2 feet in diameter locatable on the map. As a prelude to monitoring, club members have mapped a few caves, remapped a few others, and improved the details on quite a few more,

Once a detailed map of the cave is obtained it is digitally scanned, and all information on the map, except for the plan, is removed using Photoshop. Next the cave plan is rotated so that north is oriented up the page. The oriented view is then added as a layer in ArcMap and classified so that map lines show black and background is transparent. Lastly, the cave plan is placed in the correct location on a topographic map, imagery, or other base layer, using georeferencing and measuring tools. If the survey data is available this is also used to georeference the map. Often times cave survey data is not available. We feel that the survey data is not essential to establish or repeat monitoring, and if the sketch of an existing map is of high quality, establishing monitoring should take precedent over remapping the cave. In most cases, monitoring will more directly influence management than resurveying a cave that already has a useable cave map.

The georeferenced cave plan is a raster image and will lose quality the farther it is zoomed out. Also, because its background is transparent, it is difficult to see against the base layer. To remedy these problems, a polygon outlining the raster cave map and omitting internal detail is added as another layer. This second layer is a vector image that can be made visible at all scales and also colored to provide an appropriate background for the raster-image cave plan. The vector image, as with all subsequent layers, can be added as a feature class or shape file. However, adding layers as feature classes makes them more versatile and if all layers, including the cave plan, are in the same projection, the whole project can be downloaded onto a mobile device, such as a Juno.

After raster and vector image of the cave plan are created, separate layers are created for each type of monitoring. Temperature and humidity measurements, photo monitoring, and VIP monitoring, are all input into GIS by marking the location of each recorded measurement, photo point, or feature, at the appropriate location on the raster cave plan by

Figure 3. Example of VIP Mineral Monitoring



using the pencil tool in editor. VIA monitoring is input in the same way, except a polygon layer is used instead of a point layer. As points (or polygons) are drawn, the description of the feature represented at the point (or polygon) is added to the layer's attribute table along with other information that was collected in the cave. Separate VIP and VIA layers are created as needed for different types of resources such as mineral features, biological features, paleontological features, cultural resources, and so on. Also, hyperlinks for photos are established as photo points are drawn. An example of a map showing VIP Point data is presented in Figure 3 and part of the attribute table for these points is presented in Table 1.

Classification of Feature Type, Significance, Fragility, and Condition

The Cave Club classifies monitored cave features for: (1) type, (2) significance, (3) fragility, and (4) condition. The classification is intended to be used as a guide for planning and assessment of management activities. The classification takes on slightly different meaning depending on whether the features are mineral, biological, cultural, or so on. For brevity, we focus on explaining the classification of mineral features herein.

Type

A one- to four-word description of the type of feature is included in a separate column in the attribute table. These are standardized for a project (or within an area) so that the types can be queried and represented graphically. Examples of feature types for biology include bat urine stain, wood rat midden, bone, insect exoskeleton, and so on. Examples of feature types for mineralogy include calcite drip and seep deposits, gypsum deposits, calcite subaqueous deposits, and so on. Feature type classification can be used to determine the abundance and distribution of features within a cave. It also can be used to compare and establish relationships between different types of features.

Significance

Features are classified based on their local and regional abundance. Significance can be used to prioritize management to help protect rare and unusual features.

Table 1. Attribute Table for Map in Figure 3

Pt#	Description	Significance	Fragility	Condition 2011	LAC
M1	Popcorn on most of wall (polyline)	Common	resistant	No observable impact	indicator
M1	Popcorn on most of wall (polyline)	Common	resistant	No observable impact	indicator
M2	2 – 2.5 x ½ x 3 in draperies about 1 ft broken	Common	resistant	Severe 2	indicator
M3	Flowstone on wall (polyline)	Common	resistant	No observable impact	indicator
M3	Flowstone on wall (polyline)	Common	resistant	No observable impact	indicator
M3a	Flowstone at climb-down traffic wear (polyline)	Common	resistant	Light	indicator
M3a	Flowstone at climb-down traffic wear (polyline)	Common	resistant	Light	indicator
M3b	Flowstone at climb-down across from climb-down (poly)	Common	resistant	No observable impact	indicator
M3	Flowstone on wall (polyline)	Common	resistant	No observable impact	indicator
M3c	Stalactites and sodastraws along ceiling drop, Less than 25% broken (polyline)	Common	resistant	No observable impact	indicator
M4	Soda straws from 1 to 2 in about 20 in area about 25% are broken (poly)	Common	Fragile	Heavy	indicator
M5	Stalactites, snowballs on ceiling cover about 20% of surface, Stalactites from 1 in to 3 feet long. Less than 25% broken.(poly)	Common	resistant	Heavy	indicator
M6	Column 3 in dia X 1 ft long	Common	resistant	No observable impact	indicator
M7	3 – 6 in diameter base stalactites all broken	Common	Fragile	Severe 3	indicator
M12	Stalactites at ceiling drop most are broken (polyline)	Common	Very fragile	Severe 3	indicator
M7a	2 – 2 in dia stalactites both broken	Common	Fragile	Severe 3	indicator
M8	Draperies Most have tips broken	Uncommon	resistant	Severe 1	indicator
M9	Flowstone covers most of wall	Common	resistant	No observable impact	indicator
M10	Flowstone and draperies on wall Flowstone is n top ¼ of wall, Draperies go down 3 /4 of way from top. Draperies are up to 1 foot wide. Tip of one is broken (poly)	Uncommon	resistant	Heavy	indicator

1. Common - Feature is present and abundant in almost all caves in the local or management area.

2. Uncommon - Feature can be observed in about one-third of caves in the local or management area.

3. Locally Significant - Feature can only be observed in one to three caves in the local or management area.

4. Regionally Significant - Feature can only be observed in a few caves in the state or region.

Fragility

Mineral features are classified in general terms for fragility. This classification is based on the impression of club members as to how likely the feature is to be damaged by humans. Fragility classification can be used to develop travel routes through caves. Also, relating feature damage to feature fragility will indicate how careful visitors are being.

1. Resistant - Feature seems unlikely to be accidentally damaged by human visitors at the current rate of visitation. Disturbance would involve an intentional act of vandalism.

2. Fragile - Feature may be inadvertently damaged by careless visitors who are unaware of the features

sensitivity. However, conscientious visitors are able to minimize disturbance.

3. Very Fragile - Feature is likely to be damaged by even the most careful visitors.

Note: The above fragility classes are used with the same explanation for paleontology and cultural resources, but for biology the verb "disturbed" is substituted for "damaged" and the class "fragile" becomes "susceptible to disturbance" and "very fragile" becomes "very susceptible to disturbance".

Condition

Features are also classified based upon the amount and severity of human-caused damage or impact. Condition classification is completed each time monitoring is completed so changes can be assessed to evaluate the effectiveness of management at limiting visitor impacts. The condition class for resources that extend over an expansive area is averaged over that area. This can lead to some variance in precise interpretation. We have been experimenting with methods such as laser projection of standardized grids and photo correlation, but even without these improvements condition classification can provide managers with valuable information. In general, all types of resources are assigned condition classes. These are: no observable impacts, light impacts, heavy impacts, or severe impacts. Explanations of classification for most mineral features are explained below:

1. Impacts to silt, mud, or sand floor surfaces

A. No Observable Impact - The feature could have been altered by human activities, but no impacts can be observed.

B. Light Impacts - Light brushing of surface covering less than 25% of surface area OR faint depressions covering less than 25% of surface area.

C. Heavy Impacts - Trenching is less than 1/4" deep OR brushing of more than 25% of surface area OR noticeable depressions covering 25 to 75% of surface area.

D. Severe 1 Impacts - Trenching greater than 1/2" deep OR depressions 1/2" deep or greater OR depressions cover 50 to 75% of the surface area.

E. Severe 2 Impacts - 75 to 100% of surface is completely altered by 1/2" or greater depressions.

F. Severe 3 Impacts - Pits and fill caused by human digging activities half altered natural surfaces OR human activities have altered natural water flow and flooding patterns resulting in redepositon of deposits.

2. Impacts to floor surfaces covered by cobbles or angular rocks.

A. Light Impacts- Mud smears, boot marks, or other traffic wear cover less than 50% of the tops of the cobbles or rocks.

B. Heavy Impacts - Mud smears, boot marks, or other traffic cover 50 to 100% of the tops of the cobbles or rocks.

C. Severe 1 Impacts - Mud or other traffic-caused debris is deposited in thick layers 1/4" or greater OR cobbles

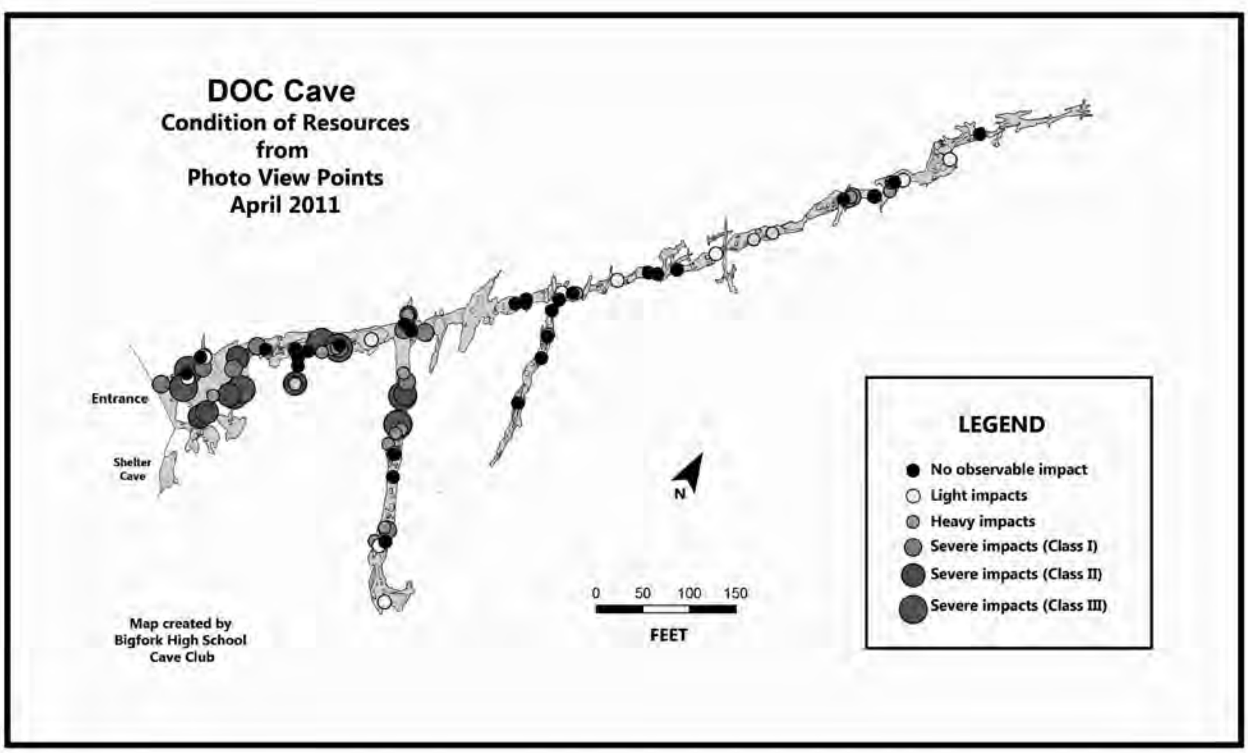


Figure 4. Example of Feature Conditions

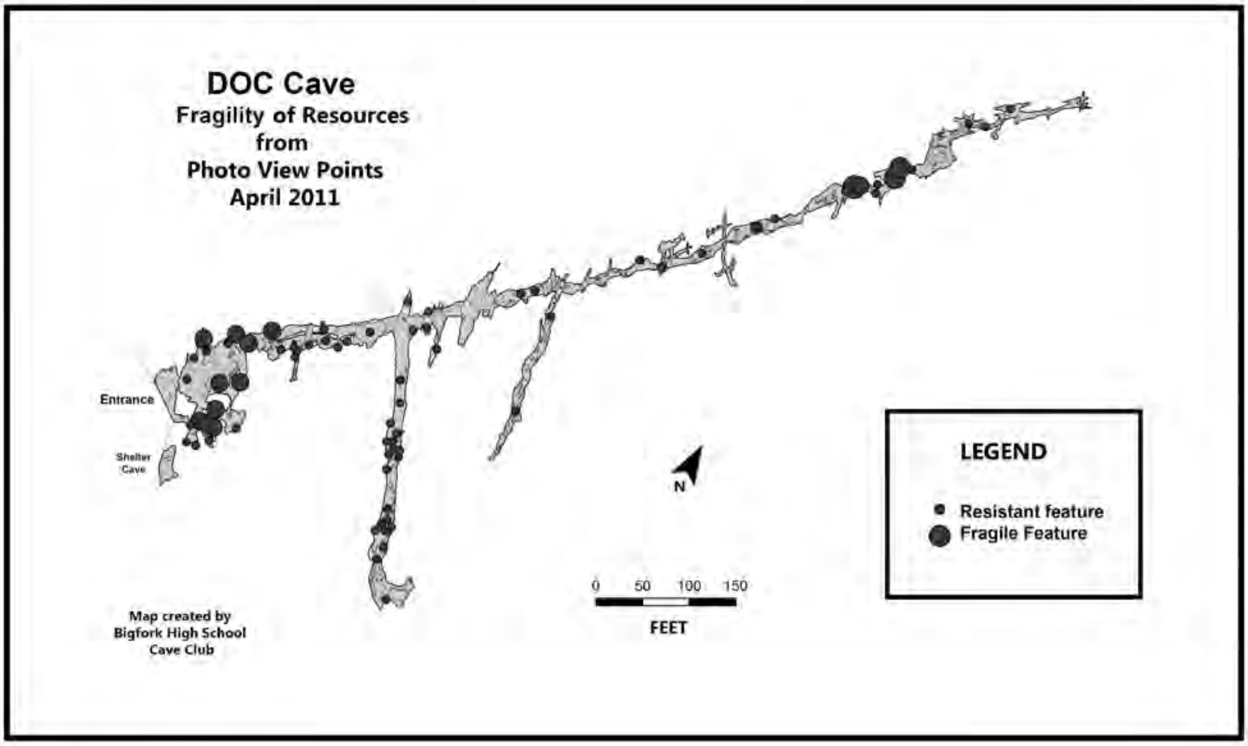


Figure5. Example of Feature Fragility Represented Graphically.

or rocks are rolled to side of a pathway to form a trench that is about half as deep as the diameter of the larger cobbles or rocks.

D. Severe 2 Impacts - Mud or other traffic caused debris has mostly covered cobbles or rocks, but they are recognizable as cobbles or rocks OR a trenching is greater than the diameter of the larger cobbles or rocks.

E. Severe 3 Impacts - Pits and fill caused by human digging activities have altered natural surfaces OR human activities have altered natural water flow and flooding patterns resulting in redepositon of deposits.

3. Impacts to bedrock or flowstone floor surfaces.

A. Light Impacts - Mud smears, boot marks or other traffic wear cover less than 25% of surface area.

B. Heavy Impacts - Mud smears, boot smears, or other traffic wear cover 25 to 50% of surface area.

C. Severe 1 Impacts - Mud smears, boot marks, or other traffic wear cover 50 to 75% of surface area OR mud or other human transported debris is deposited in thick layers up to 1/4" OR up to 10 % of surface is chipped or broken from traffic wear.

D. Severe 2 Impacts - Mud smears, boot marks, or other traffic wear cover 75 to 100% of surface area OR mud or other human-transported debris is deposited in thick layers over 1/4" thick OR over 10 % of surface is chipped or broken from traffic wear.

Severe 3 Impacts - Surface has been intentionally altered by "mining" or vandalism or other activities involving intentional breakage of the surface.

4. Impacts to Speleothems

A. Light Impacts - Speleothem(s) lightly stained with mud smears, skin oils, or other deposits left by human traffic.

B. Heavy Impacts - Surface of the speleothem(s) altered by humans touching the surface OR a layer of mud or other human-transported debris up to 1/16" has been deposited on the surface.

C. Severe 1 Impacts - Up to 25% of speleothem(s) broken.

D. Severe 2 Impacts - 25 up to 50% of speleothem(s) broken.

E. Severe 3 Impacts - Over 50% of speleothem(s) broken.

Analysis of Cave Resources using GIS

GIS is a wonderful tool to organize and analyze cave monitoring information. As an example of the program's capabilities, consider the amount of raw data collected by the cave club when they established monitoring for 11 caves in Grand Canyon National Park. Their data includes 474 located photo points with photos, descriptions, azimuth, and classification of views; 329 located mineral VIP points with descriptions and classifications; 153 located VIA mineral feature polygons with area calculations; 251 located VIP biological points with descriptions; 99 located biological polygons with area calculations; 57 located temperature and humidity measurements; 26 located VIP cultural resource points with descriptions and classification; and 5 VIA cultural resource polygons with area calculations.

At the park's request the club has submitted their data in two formats: a written document, which evolved into a 233 page report with a photo CD, and a 5.66 GB digital folder containing all the GIS layers and hyperlinked photos. Arguably, it is probably prudent for data to be submitted in multiple formats, but imagine how overwhelming it is to wade through 233 pages of text, photos, and maps contained in a written report when GIS layers can be easily queried, analyzed, and displayed. In fact, data in the GIS layers can be represented and analyzed in many ways that are too cumbersome to present in a conventional written report. A few examples of how the cave club has used GIS to represent and analyze monitoring data are explained below.

Graphical Representation of Resource Conditions

Condition classes are assigned number value codes in a separate column in the attribute table. For example, "no observable impacts = 0, light impacts, = 1, heavy impacts = 2, and so on. These are then symbolized in the properties menu and represented as graduated symbols of different colors. An example of a map exported out of GIS, which shows conditions of cave features as viewed from photo view points is presented in Figure 4. The map shows a concentration of severe impacts near the front of the cave. The impacts drop off at a difficult climb, which probably selects visitors to the back of the cave. However, examination of resource fragility (see Figure 5), which were symbolized in a similar fashion as were condition classes, shows that most fragile resources are in the front part of the cave. Furthermore the few fragile resources that are in the back are heavily and severely impacted. This analysis implies that although the difficult climb may select visitors to the back of the cave, it doesn't make the selected visitors less likely to damage fragile cave resources.

Evaluation of the Extent and Distribution of Feature Types

Points and polygons representing cave features can be coded and used to illustrate the distribution of selected types of features. Figure 6 shows the distribution of bat sign near in the entrance area of a cave. This information could be useful in directed future bat research or in design and installation of gates.

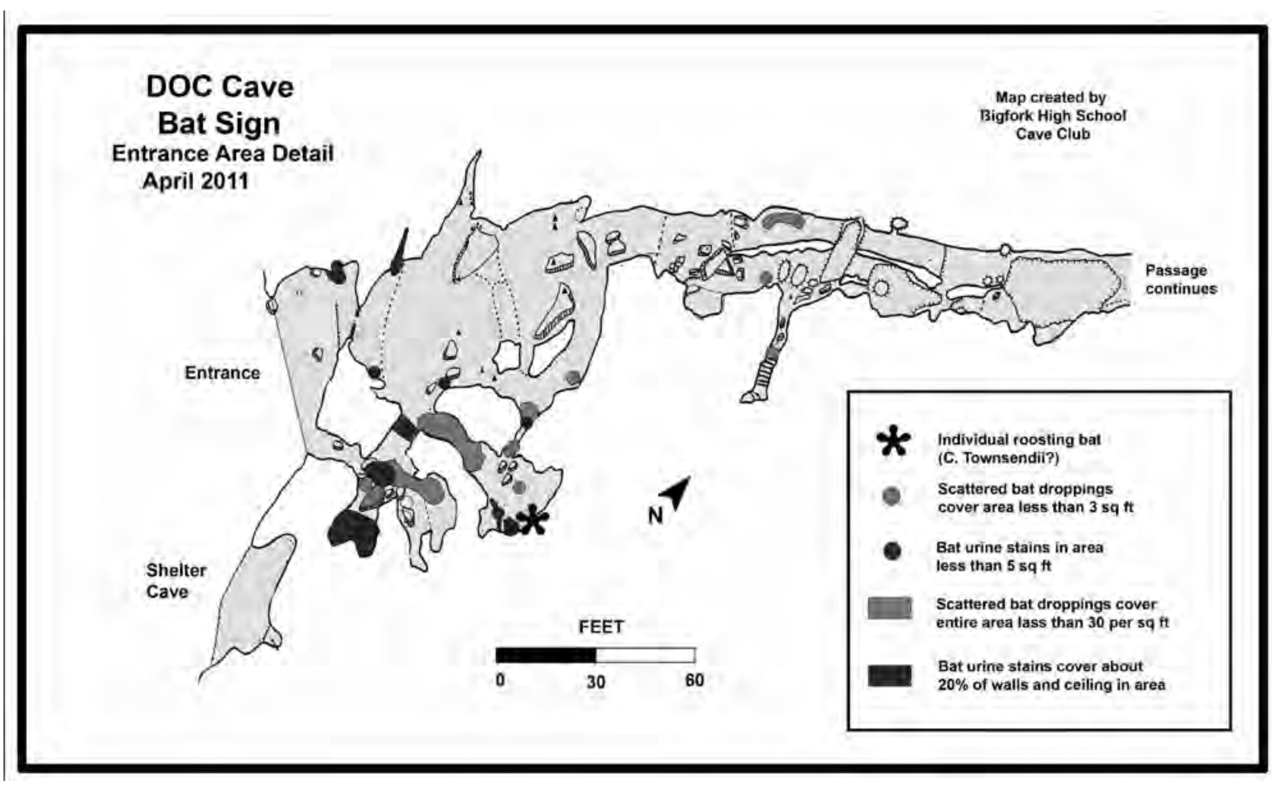
Calculating and Comparing Area of Polygons

GIS will automatically calculate the area of polygons in a geodatabase. Calculated areas that represent features of similar types can be summed to determine the extent of the type of features they represent. Figure 7 shows the condition of fragile floor surfaces represented as classified polygons. Table 2 lists the total area of each condition class and percentage of the total area of fragile floor surfaces. This information can be used to assess current conditions and quantify future changes.

Calculating Statistics and Averages for Classified Features

GIS can calculate averages and other statistical properties for feature classes that have been assigned number values. Table 3 presents the average condition of features as viewed from photo points for nine caves in Grand Canyon National Park. As in the first example, condition classes are assigned a number value code: "no observable impacts = 0, light impacts, = 1,

Figure5. Example of Feature Type Distribution



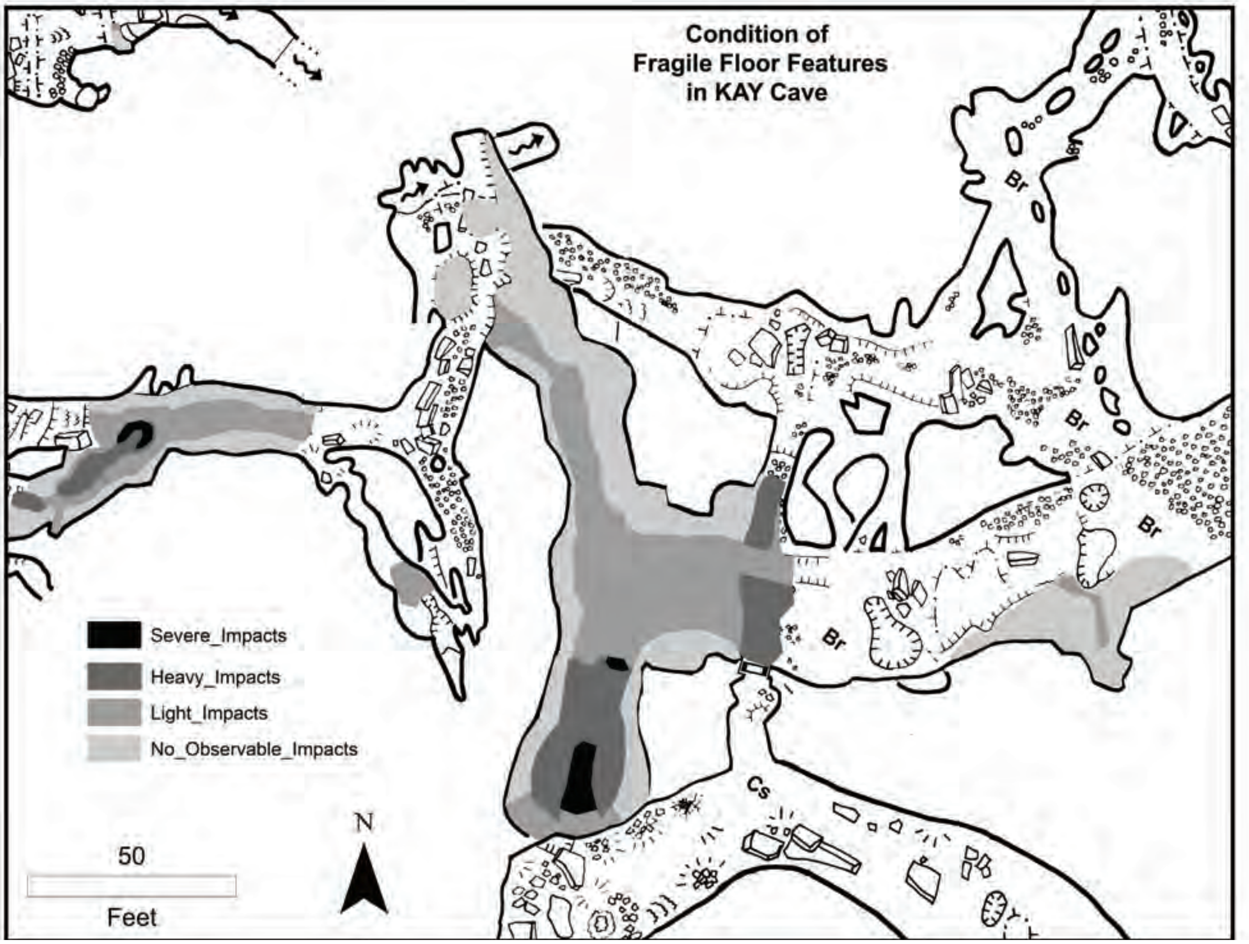


Figure 7. Fragile Floor Surfaces Represented as Classified Polygons

heavy impacts = 2, and so on. Condition class averages can be used to evaluate the overall condition of features in each cave. In this example, caves with condition averages greater than 1.2 are in poor overall condition, and those with averages less than 1 are in good overall condition. Table 3 also gives the standard deviation of each condition average. These can be used to get an impression of how concentrated impacts are within a cave. In general, a lower standard deviation indicates the condition of features is more similar and visitor impacts are spread out more uniformly through the cave. Whereas, a higher standard deviation indicates the condition of features is more variable and impacts are probably concentrated at a few locations.

Directly Linking Monitoring and GIS to Management

Most of the time monitoring only indirectly influences cave management. In a common scenario managers are compelled to take action after reading reports and viewing presentations in which monitoring has shown dramatic changes to cave resources. Unfortunately, this almost always happens after much resource damage has occurred. Furthermore, it is more common that monitoring is not at all connected to management and management decisions are made based on incidental observations or impressions.

The Bigfork High School Cave Club has developed a simple procedure to directly link monitoring to management using GIS and a Limits of Acceptable Change (LAC) model. LAC was developed in the 1980's by the US Forest Service for planning and management of wilderness (McCool and Cole, 1997). In theory, the procedure developed by the cave club can be designed to detect small changes before significant or large numbers of resources become severely damaged using GIS to facilitate analysis of changes. Once monitoring and GIS indicate damages have reached a threshold of change (or LAC), managers are prompted to initiate predetermined management actions. Using Poia Lake Cave in Glacier National Park as an example, the procedure is further explained below.

Poia Lake Cave is slightly over a mile long with an annual visitation of about 150 people. The cave contains some calcite and moonmilk flowstone and a few stalactites. It also contains thick deposits of wood rat middens and provides habitat for a small number of individually roosting bats and cave adapted microinvertebrates. Monitoring for features is linked to management in a multi-step process.

First, features are assigned a LAC management class based upon significance, aesthetics, and social input.

Impact Class	Area of floor in class (meters)	Percent of total fragile floor
No Observable Impacts	409.15	49.7
Light Impacts	234.38	28.5
Heavy Impacts	157.05	19.1
Severe Impacts	21.83	2.7

Total of fragile floor = 822.41

Table 2. An Example of Area Calculations for Expansive Feature Classes

Management classes are explained below:

1. Indicator – It is recommended the feature be managed as an indicator of human-caused changes that could eventually lead to damage of other more valuable resources.

2. Conserve – Feature is of high scientific and aesthetic value, but is relatively common or resistant to human disturbance. It is recommended the feature be managed so that visitors can experience and enjoy the feature in near pristine conditions.

3. Preserve – Feature is of very high scientific and aesthetic value, is relatively rare, and could be easily damaged by human visitors. It is recommended the feature be managed so that it will be maintained in near pristine conditions, even if this requires limiting visitor access.

For Poia Lake Cave, all features were assigned to the indicator class.

The second step in the process involves setting an LAC threshold for each management class and committing managers to a predetermined management action should the threshold be exceeded. For Poia Lake Cave it was decided that if monitoring detected any changes to conserve or preserve features, or change was detected at 5% or more of the indicator features, managers would meet to develop a more restrictive management.

The third step involves implementing predetermined management based on monitoring findings. Monitoring for Poia Lake Cave was established in 2005 and repeated in 2009. Monitoring showed no change to conserve or preserve features, but changes to 9% of the indicator resources. Most changes were minor, but to prevent more serious damage managers met and decided to place a sign in the entrance of the cave, increase patrols, and repeat monitoring in two years to see if even more restrictive management is warranted.

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We are especially grateful to our mentors and heroes. These people helped us develop our methods and worked with us as partners: Jack Potter, Chief of Science and Resource Management, Glacier National Park (retired); Kyle Johnson, West Lakes Wilderness Coordinator, Glacier National Park; Denny Rae, GIS specialist, Flathead County, MT (retired); Lisa Bate, Wildlife Biologist, Glacier National Park; Richard Menike, GIS specialist, Glacier National Park; Ben Sainsbury, GIS specialist, Yavapai County, AZ; Steve Rice, Hydrologist and Cave Specialist, Grand Canyon National Park; Colter Pence, Wilderness, Trails, and River Coordinator, Flathead National Forest; Charlie Fitzpatrick, ESRI Education Director; and Ricky DeHerrera, District Ranger, Hungry RD, Flathead National Forest. We also greatly appreciate our financial sponsors; our projects would not have been possible without funding and support from members of the Northern Rocky Mountain Grotto, Gonzo Guano Gear, ESRI, Charlie Fitzpatrick (Education Director of ESRI), The Charlotte Martin Foundation, The Angora Ridge Foundation, members of the Flathead Chapter of the Audubon Society, The Glacier National Park Fund, Best Buy for Business, and Plum Creek Foundation.

Cave	# Photo Points	Condition Average for Photo Points	Standard Deviation for Averages
ART	46	0.439	0.607
DOC	103	1.553	1.60
DOC (before climb)	70	2.014	0.85
DIM	8	1.5	1.322
FIN	32	0.406	0.744
GAR	17	0.764	0.730
HOP	43	0.046	0.301
NOT	47	1.085	1.426
ROS	17	1.705	1.225
TRE	43	0.883	1.165
WOW	57	0.561	0.710

Table 3. Average Condition Values for 9 Caves in Grand Canyon National Park

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The Gating of Eagle Creek Bat Cave, Arizona

Tom Gilleland
MineGates, Inc.
4980 N Campbell Ave., Tucson, AZ 85718
520.577.8945
tom@minegates.com

Abstract

Eagle Creek Bat Cave is large entranced cave located in a remote riparian canyon of Eastern Arizona. This single-roomed cave currently houses a summer colony of about 60,000 Mexican Free-tail bats. Historic roost estimates have quoted 30 million bats, but guano measurements put this number closer to 3 million. In 2001, vandals set a fire in the cave entrance that burned much of the historic guano mining workings and the guano pile. The following year bat exit counts numbered less than 10,000 bats. In 2010, MineGates, Inc fabricated and installed a huge 25 ft wide by 12 ft tall steel flyover gate to protect this unique site. Installation of this gate presented many unique challenges due to the size of the gate, and the remoteness of the location.

Seasonal Variation of Carbon Dioxide in Oregon Caves

Elizabeth Hale, GIS Specialist
Oregon Caves National Monument
National Park Service
elizabeth_hale@nps.gov

Abstract

Analysis of 10 years of atmospheric carbon dioxide data in Oregon Caves was performed to identify CO_2 sources, distribution, and variability. Preliminary analysis discovered significant seasonal variation, which correlated with results from a marble dissolution study. The highest CO_2 concentrations were found at stream level in the lower part of the cave. Peak CO_2 throughout the cave occurred in summer. Discussion will include potential interpretation of these results.

Introduction

Atmospheric carbon dioxide (CO_2) was measured in Oregon Caves as part of an inventory effort in 1992-96 and 2000 and cave monitoring 2007-10. CO_2 measurements are important for understanding the sources of CO_2 and its distribution and movement, which in turn can help explain cave meteorology and subsurface geochemical processes such as calcite deposition and condensation corrosion (Baldini *et al*., 2006). CO_2 monitoring can provide evidence of measurable climate changes or visitor impacts in the cave environment, provided there is a proper baseline analysis to establish background levels and relaxation times and to identify variables (James, 2003). The objectives of this analysis were to explore CO_2 concentrations and variations in the ten-year data set and elucidate the major sources and controls of CO_2 in Oregon Caves.

Seasonally, CO_2 is more concentrated in Oregon Caves between May and November, but even during winter, cave CO_2 levels are higher than on the surface. Seasonal variation in CO_2 often occurs as a function of the annual surface temperature cycle that influences cave airflow (Batiot-Guilhe *et al*., 2007; Eberhard *et al*., 2005; Milanolo & Gabrovšek, 2009). In the absence of air movement, CO_2 is concentrated near its source, not at the lowest vertical level (Badino, 2009). Therefore CO_2 sources may be differentiated by examining the spatial distribution and seasonality of CO_2 data in light of other data sets such as airflow, barometric pressure, temperature, water geochemistry, and water infiltration into the cave.

Oregon Caves

Oregon Caves National Monument is located in the Siskiyou Mountains in southwestern Oregon between Interstate-5 and the Pacific coast. Oregon Caves is a marble cave that showcases regional geology and is a habitat to eight likely endemics. The total surveyed length of the cave is 4.8-km. Approximately 49,000 visitors tour the cave annually along a 1.0-km developed route and, to a far lesser extent, a 0.2-km off-trail caving route. Tour season is open mid-March to November.

Oregon Caves' five entrances are situated between 1,219 m and 1,286 m elevation (Figure 1). The lowest cave entrance, Main Entrance, is the resurgence of Cave Creek, a sinking surface stream upslope from the cave. Underground, the River Styx, as it is called, may be differentiated between Ghost Room and Lower Cave sections, with the pirated waters of upper Cave Creek only being present in the Lower Cave. At the uppermost entrance, the manmade Exit Tunnel, airflow is limited by an air restrictor, but airflow is present in the Wind Tunnel, an enlarged passage that leads to the Ghost Room, the cave's largest room. A chimney effect between the lowest entrance and the 110 Exit creates seasonal ventilation patterns.

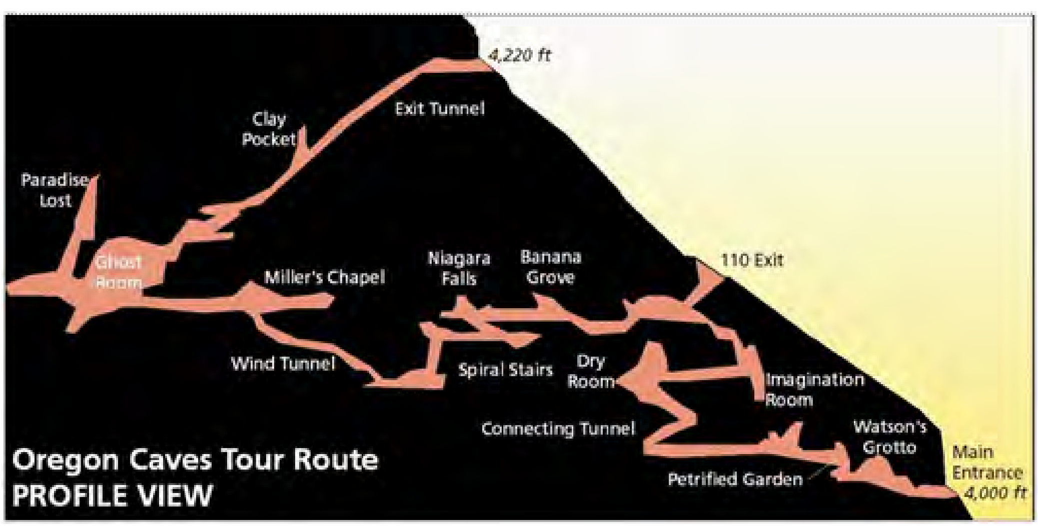


Figure 1. Cave air moves down and out of the lowest entrance in summer. An air restrictor is present in the man-made Exit Tunnel. Only the three entrances used by cave tours are shown on this profile-view illustration, but it displays the full elevation range of Oregon Caves' entrances.

Cave temperature near the 110 Exit varies as much as 13° C annually, but in deeper passages less than 1° C annually.

Literature review suggests the most probable sources of elevated CO_2 in a solution show cave like Oregon Caves are (Baldini *et al*., 2006; James, 2003):

1. Degassing from water: Soil CO_2 dissolves into vadose water, then dissolves out of the water when it is exposed to the relatively lower CO_2 levels of the cave atmosphere.

2. Human breathing: Each human breath contains approximately 40,000 parts per million (ppm) CO_2. Researchers can increase local CO_2 levels while measuring them, and visitors may create significant accumulation of CO_2 depending on the size and frequency of cave tours, the energy they expend underground, the proportion of the cave visited, and the mechanisms available to remove CO_2 from the cave.

3. Respiration of micro-organisms: In the cave, micro-organisms may be associated with natural or human-caused decaying organic matter. Above the cave, where soil CO_2 is dissolving into cave water, micro-organisms may be the main reason that soils have substantially more CO_2 than the atmosphere.

4. Flow through fractures connected to the soil: This is more common in shallow cave passages, where roots growing in ceiling fissures indicate the close proximity of soil.

Methods

In 1992-96 and 2000 atmospheric CO_2 was measured on 37 occasions near several hydrologic sites in the cave, a range of stream, pool, and drip sites, and at one surface site. Measurements were taken with a CEA Instruments Portable CO_2 Indicator model RI-411A. The meter was calibrated regularly with cartridges of known CO_2 concentrations. The measurement frequency was monthly in 1992-93, seasonal in 1994-95, weekly in summer 1995, daily for one week in July 1996, and sporadic in 2000. CO_2 was measured in close proximity to the water of interest at the sites. The time of day that measurements were taken is unknown.

In 2007-10 atmospheric CO_2 was monitored on 43 occasions at 12 monitoring sites in the cave and one surface site. Measurements were taken with a handheld TSI InspectAir CO_2 Meter model 8561; readings were collected as two-minute averages of two-second interval samples. The meter was calibrated within 24 hours prior to monitoring with gas canisters of known CO_2 concentrations. The monitoring frequency during this period was monthly and also twice a day two days in summer 2008. CO_2 was measured in the morning before the first cave tour at the low-, mid-, and upper-level of each site. Gaps in data exist for some sites that were avoided in winter months due to bat hibernation.

Between the 1990s and late 2000s data sets, five sites corresponded closely enough to allow data to be compared, though none were exactly the same location. Data were analyzed in order to determine baseline CO_2, identify when and where CO_2 is most concentrated, and explore means to differentiate the effects of airflow and likely sources of CO_2. Actual values were compared with cave-to-surface ratios of CO_2 to work around meter bias.

Results

Seasonality

CO_2 exhibits a seasonal variation in which concentrations increase through spring and summer and peak around August or September (Figure 3). At peak levels, cave CO_2 is an average six times greater than on the surface. CO_2 declines in fall, and seasonally elevated CO_2 is flushed out of the cave by December. Between December and May, cave CO_2 is an average two times greater than on the surface.

Only the surface and cave sites in the variable temperature zone near the 110 Exit do not exhibit a distinct seasonal cycle. The seasonal variation of CO_2 occurs at off-trail sites as well as along the cave tour route. The highest CO_2 concentrations recorded were at stream level in Belly of the Whale, a passage with minimal airflow; additionally, Belly of the Whale exhibits elevated CO_2 in warmer months at the stream level of the passage relative to the rest of the room (Figure 4).

The maximum recorded concentration, 2,675 ppm CO_2 on July 24, 1996, was well below the Occupational Safety and Health Administration's (OSHA) workplace safety limit of 5,000 ppm CO_2.

Variability

Baseline annual means and standard deviations were calculated from a period of 16 consecutive months of data collection between August 2007 and November 2008 (Figure 5). Annual mean CO_2 is generally greater with distance from an entrance, except for Belly of the Whale (Figure 6). Annual standard deviation is high where annual mean CO_2 is high, a reflection of the decrease in CO_2 concentrations that occurs throughout the cave in winter.

CO_2 concentrations were highly variable in data sets of consecutive weekly or daily measurements, especially at stream level of Lower Cave River Styx (Figure 7). Larger volume areas exhibited less variability than smaller rooms and passages, spatially and temporally in short, three- and seven-day data collection cycles. High visitation (300+ visitors a day) creates short-term increases of CO_2 between morning and afternoon along the cave tour route (Table 1).

Long-Term Trends

No difference in CO_2 was apparent between the 1990s and late 2000s data sets (Figure 8). Seasonal variation and cave-to-surface ratios were similar. The differences that are apparent between the two data sets are mostly within the normal range of variation established by the August 2007-November 2008 baseline, or may be attributed to other variables such as: time of day, which was unknown from the 1990s data set; spatial distribution of CO_2, as geographic locations between the two time periods were not a precise match; and human error, as the 2000s data set had more data points, which resulted in a smoother average.

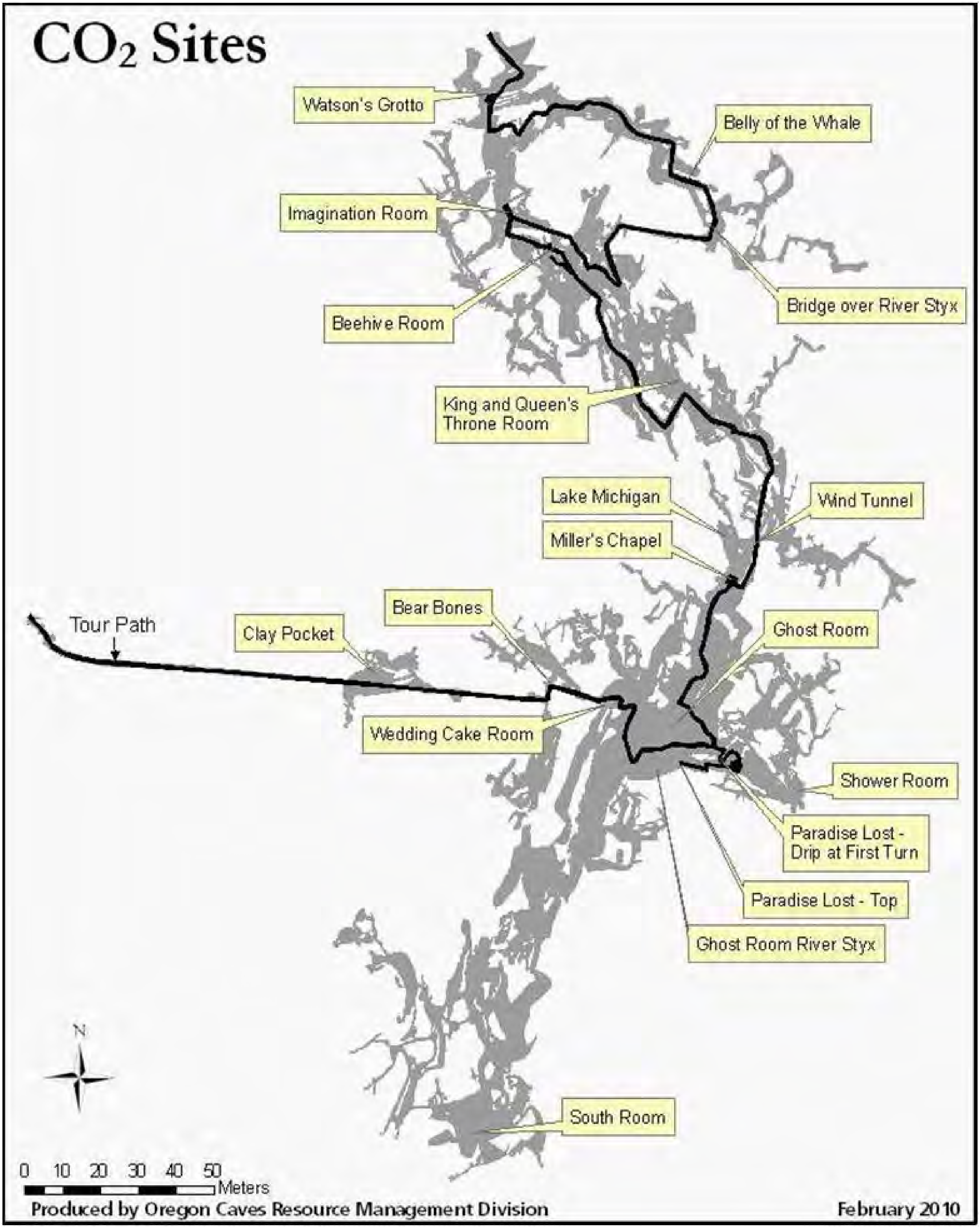
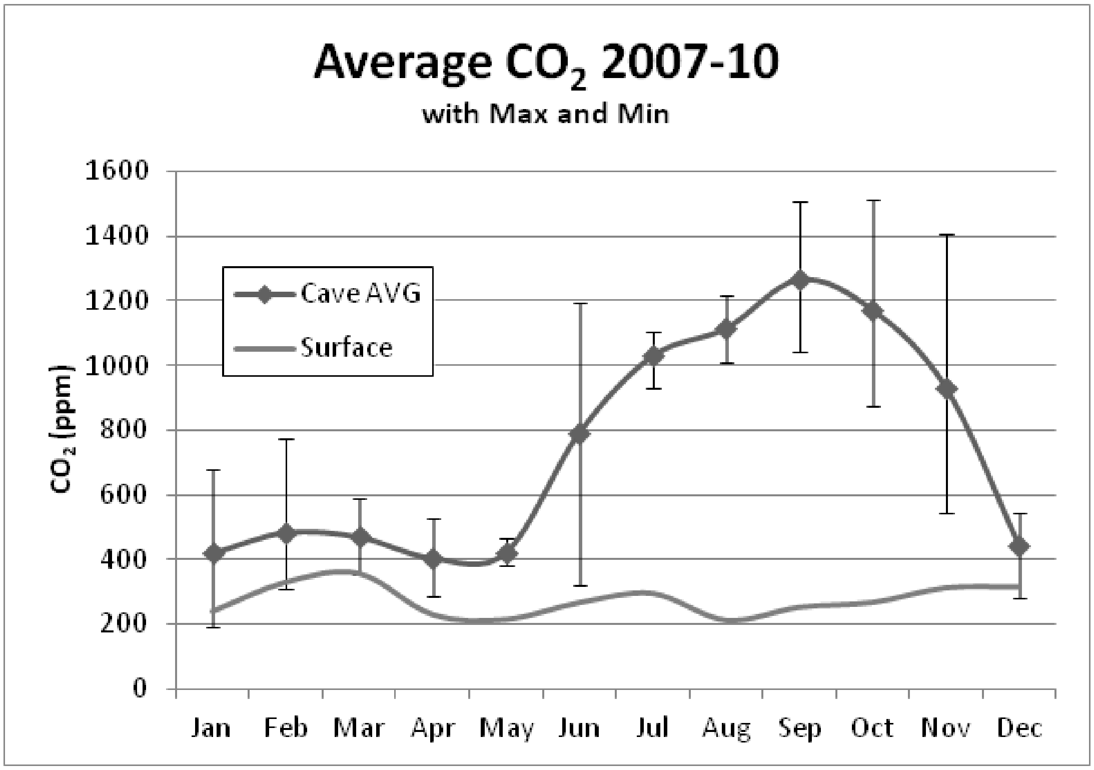


Figure 2. Map displays all sites represented in the CO2 data set. Sites visited in 1992-96 and 2000 included: Bridge over River Styx, Imagination Room, Lake Michigan, Ghost Room, Shower Room, Paradise Lost, and Wedding Cake Room. Sites visited in 2007-10 included: Watson's Grotto, Belly of the Whale, Imagination Room, Beehive Room, King and Queen's Throne Room, Wind Tunnel, Miller's Chapel, Ghost Room, Paradise Lost, Bear Bones, Clay Pocket, and South Room.



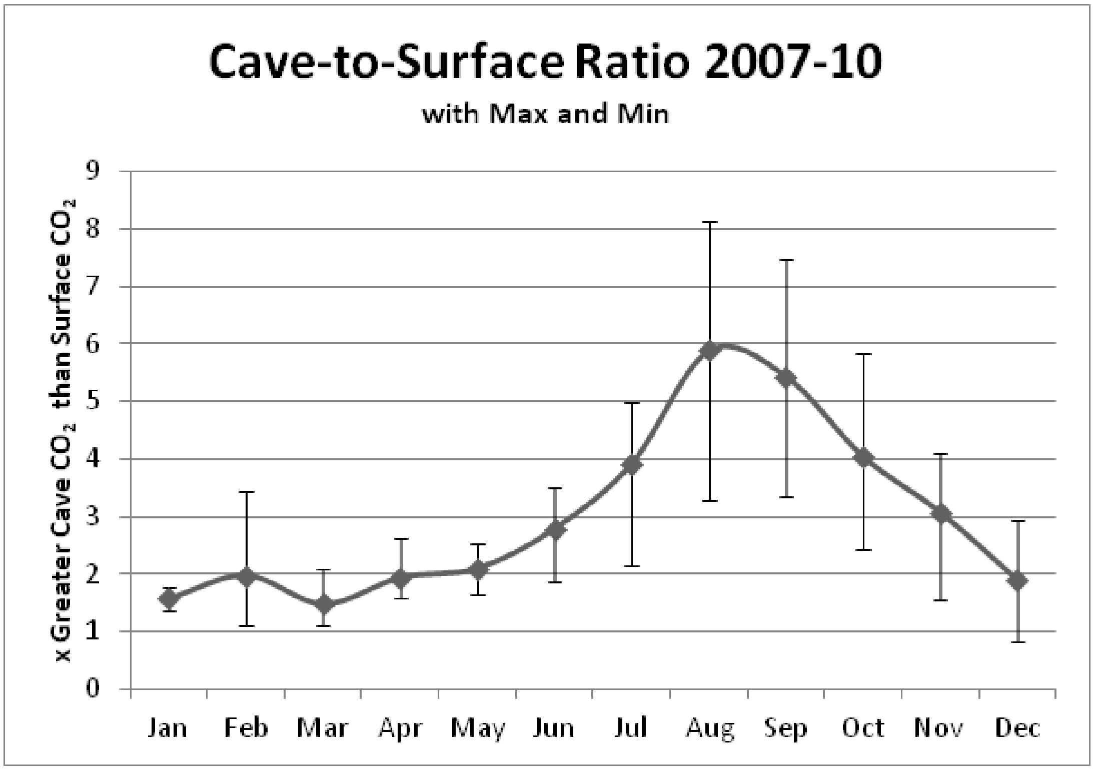


Figure 3. Seasonal variation of CO2: Seasonally elevated CO2 is evident from CO2 values and the cave-to-surface ratio. Average cave CO2 for 2007-10 was calculated from the following sites in the constant temperature zone: Bear Bones, Ghost Room, Miller's Chapel, Paradise Lost, and South Room.

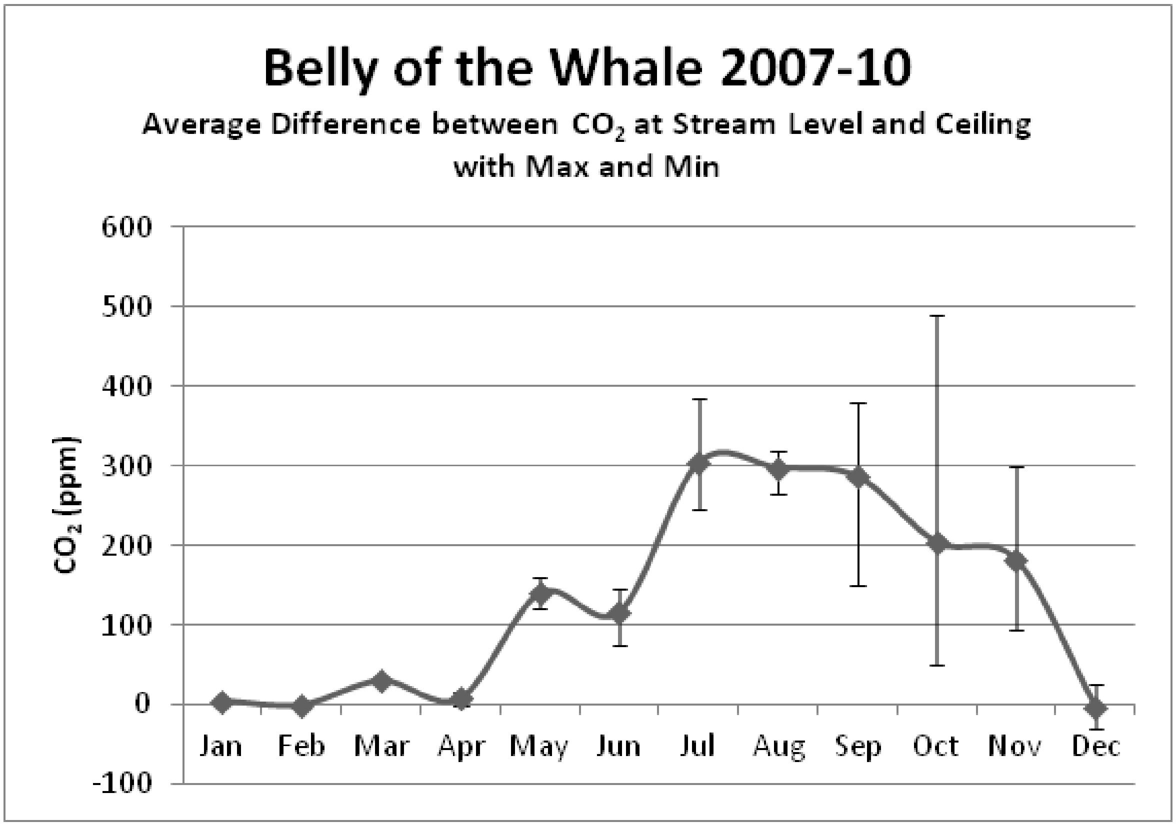


Figure 4. CO2 concentrations diverged seasonally between the stream and ceiling levels of Belly of the Whale, a passage that has a ceiling height of about 4.5 meters. The highest concentrations measured anywhere in the cave in 2007-10 were at stream level in Belly of the Whale

Discussion

Airflow

Cave ventilation appears to be the strongest regime controlling the seasonal variation of CO_2 (Figure 9). This is most apparent in cooler months when CO_2 concentrations are relatively low and constant. Winter airflow acts upon radon (^{222}Rn) the same way, substantially reducing concentrations at most sites (Figure 10). The relationship between CO_2 and airflow may be more firmly established through further study of Oregon Caves' airflow dynamics.

Visitation

The seasonal variations of CO_2 and visitation bear some similarity (Figure 11). Because Oregon Caves has many entrances and substantial airflow in summer, when the heaviest visitation occurs, it was thought prior to this analysis that human contribution to cave CO_2 was negligible. Overall the results support this hypothesis, primarily in that CO_2 levels increase seasonally at all sites, not just the ones near the tour route. In the 1990s data set this was observed in the Shower Room, an off-trail dome, and in the 2000s in the South Room, the second largest room in the cave, which receives no more than 16 visitors a day from caving tours and resource management staff in summer, and fewer or none from fall to spring.

However, the CO_2 increases of up to 119% along the tour route between morning and afternoon in summer 2008 indicate that summer visitation rates have at least a limited, short-term effect (Table 1). Additional monitoring to compare those concentrations to changes overnight, as well as measurements at additional off-trail sites, would further inform whether visitors may have an incremental effect in building up cave CO_2. But certainly any effect visitors have does not last beyond several months, as all seasonally elevated CO_2 is effectively flushed out of the cave in winter. And since human-caused CO_2 increases do not approach unsafe concentrations, anthropogenic CO_2 does not raise any management concerns for Oregon Caves.

Cave Stream

It is unclear whether seasonally concentrated CO_2 in Belly of the Whale at the stream level relative to the ceiling derives from degassing stream water, airflow differences between upper and lower passage levels, or both. Notably, CO_2 is also usually more concentrated at the stream level of Lower Cave River Styx in Watson's Grotto, though this trend was not as distinctly seasonal in the data set. Possibly upper-level Belly of the Whale is ventilated by the air restrictor in nearby Connecting Tunnel, opened as often as four times an hour for cave tours to pass through on a busy summer day. Watson's Grotto, too, may have its own airflow differences affecting the vertical distribution of CO_2, since it is located just inside the breezy lowest entrance.

The seasonal variation of stream-level CO_2 and marble

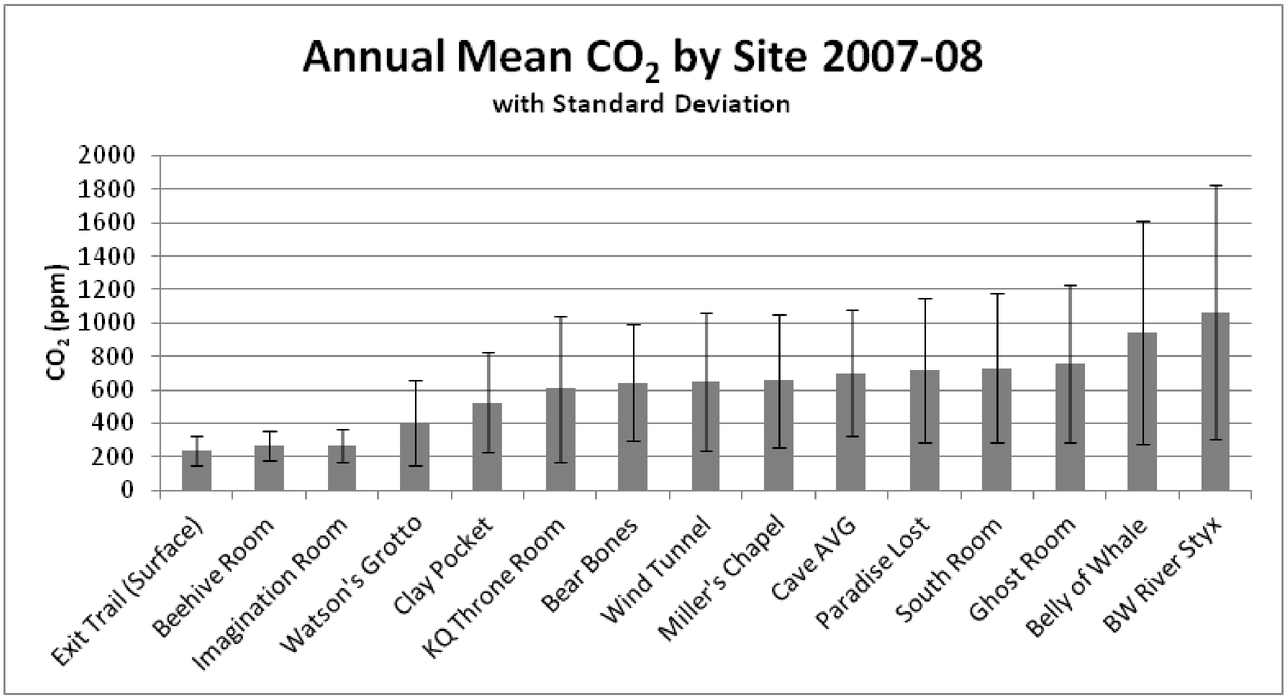


Figure 5. August 2007-November 2008 baseline: Standard deviations, represented by the error bars on the graph, increase with annual mean, a reflection of the low CO2 concentrations found at all sites in winter.

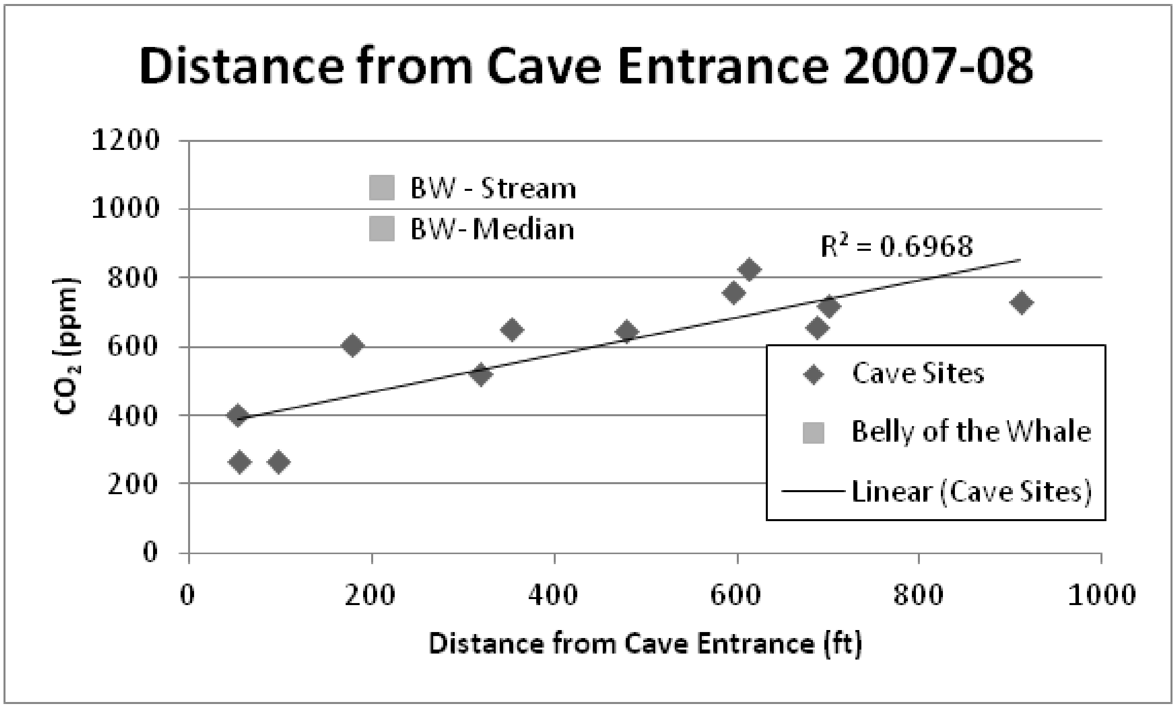


Figure 6. Annual means generally increase with distance from a cave entrance. Note the outlier data points that represent stream-level and median CO2 annual means at Belly of the Whale.

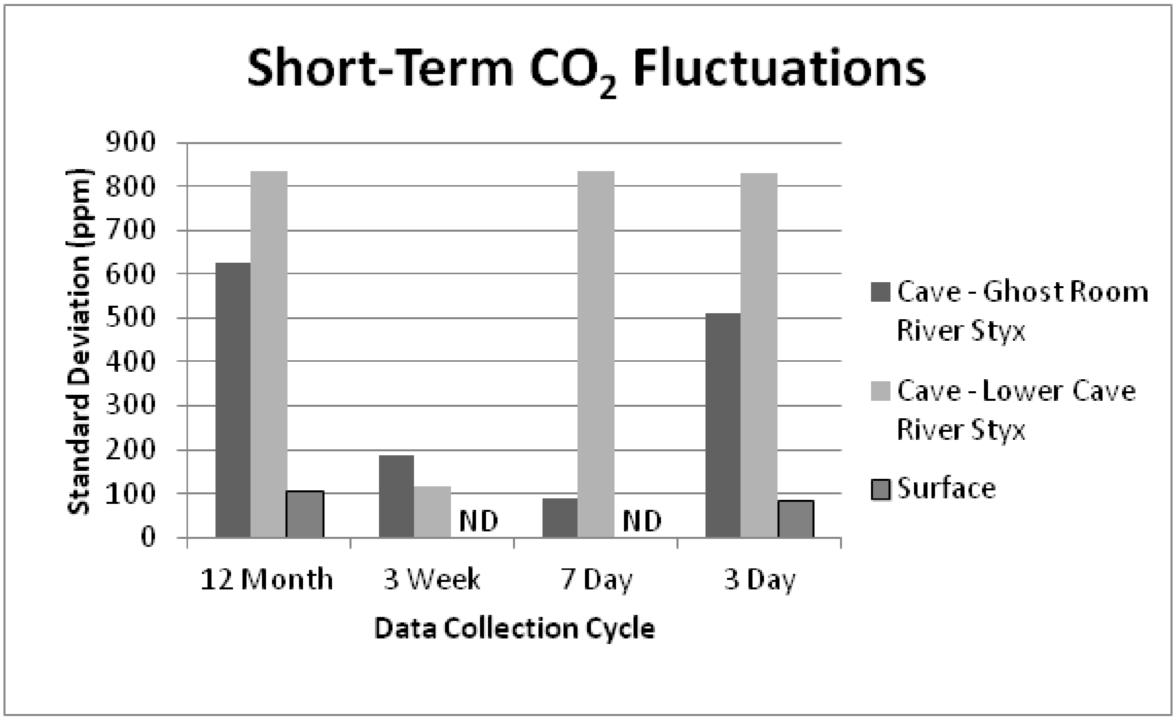
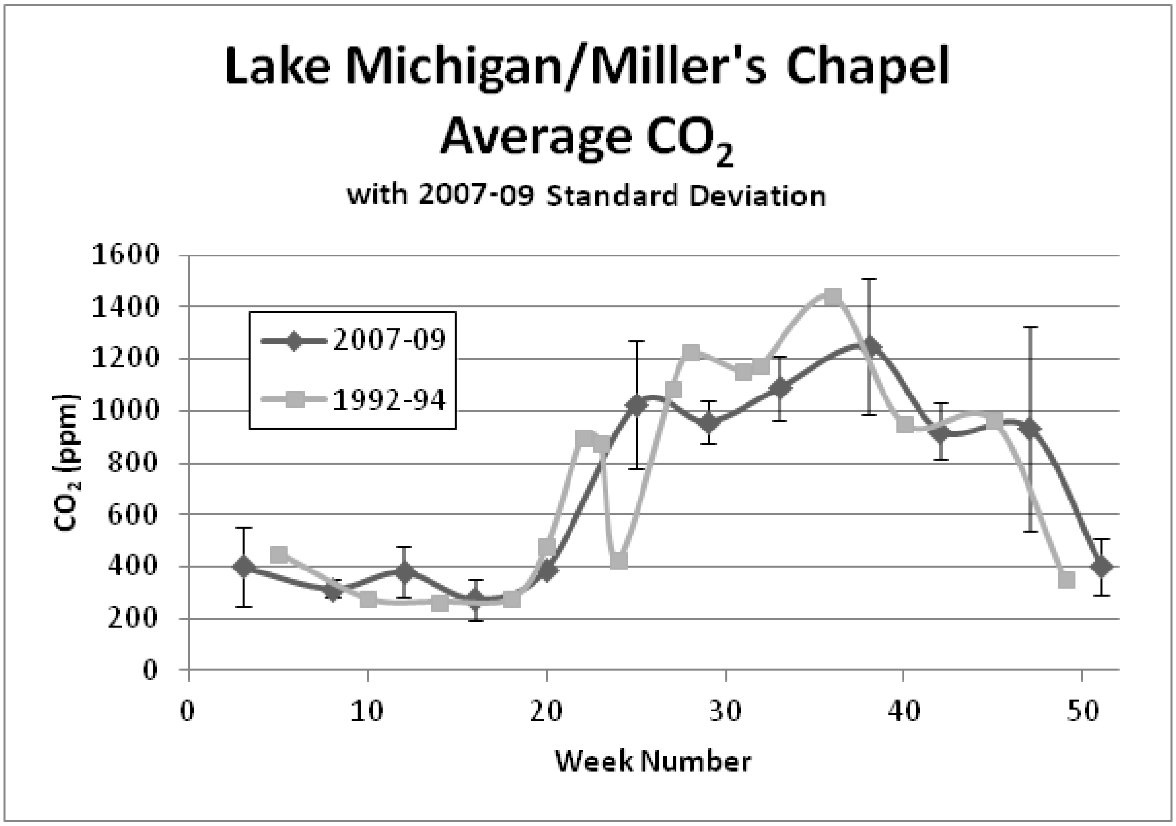


Figure 7. Standard deviations in cave CO2 were variable and occasionally high across short-term data collection cycles: annual standard deviation for the period December 2007 - November 2008 was compared to weekly measurements in July 1995 and daily measurements July 18-24, 1996 and Oct 4-6, 2010. No data (ND) was collected at the surface site in the three-week and seven-day data collection cycles.

Site	Jul 17, 2008		Aug 18, 2008	
	PPM	%	PPM	%
Watson's Grotto	140	20	390	48
Belly of the Whale	430	27	1050	84
Beehive Room	130	59	340	110
Wind Tunnel	110	12	350	34
Miller's Chapel	90	9	340	35
Ghost Room Platform	70	8	240	24
Ghost Room Floor (tour path)	-10	-1	20	2
Paradise Lost	480	62	940	119
Bear Bones	190	19	510	54
Clay Pocket	120	13	80	8
Surface	240	ND	-20	-13

Table 1. Change in CO2 Between Morning and Afternoon



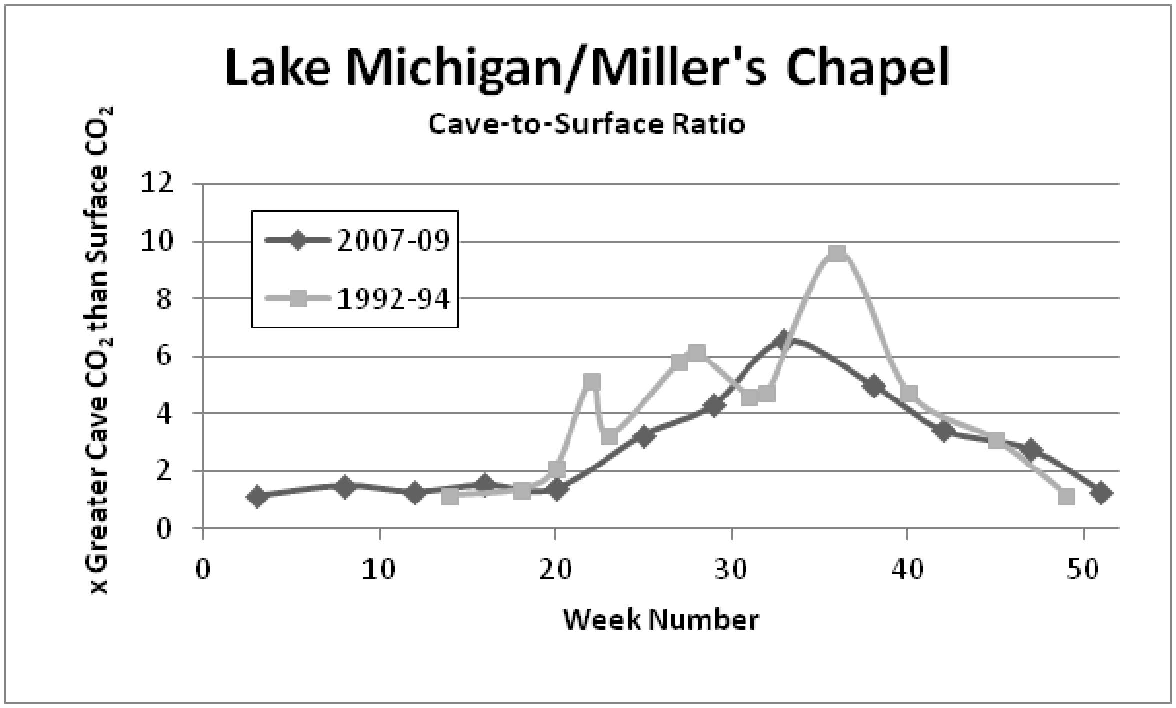


Figure 8. Lake Michigan is a pool toward the back of Miller's Chapel, and one of the sites from the 1990s data set close enough to a site in the 2000s data set to be compared. A comparison analysis suggested that no long-term shifts occurred in CO2 concentrations or seasonal variation between decades. There is one notable outlier of 425 parts per million CO2 on June 5, 1994.

dissolution in the Lower Cave River Styx bear some similarity (Figure 12). Marble dissolution rates measured in Lower Cave River Styx in 2008-09 revealed that higher rates of dissolution occur after peak discharge, which is usually in May, and through summer (Hale, 2010). However, addressing the questions raised by this observation in the data, such as why marble dissolution is seasonal and how discharge, snowmelt, and surface processes affect these phenomena, was beyond the scope of this paper though of great interest for understanding cave processes and characterizing stream dynamics as well as interpreting CO_2 measurements.

Conclusion

Having established a CO_2 baseline for Oregon Caves and conducted a literature review, the park is better positioned to interpret future data. While it is evident that airflow is a major CO_2 control, CO_2 sources were suggested but not abundantly clear from the data alone. Further inquiries of the data could involve spatial analysis with GIS, more intensive data collection during transition periods to and from low winter CO_2 levels, further integration of CO_2 data with water geochemical studies, and characterization of airflow patterns at sites where CO_2 is monitored.

Though no long-term trend was detected between the 1990s and 2000s, cave CO_2 dynamics have the potential to respond to shifts in precipitation and water infiltration and indicate changing cave climate regimes due to surface climate changes. The National Park Service will continue to monitor cave CO_2 as part of its cave monitoring program.

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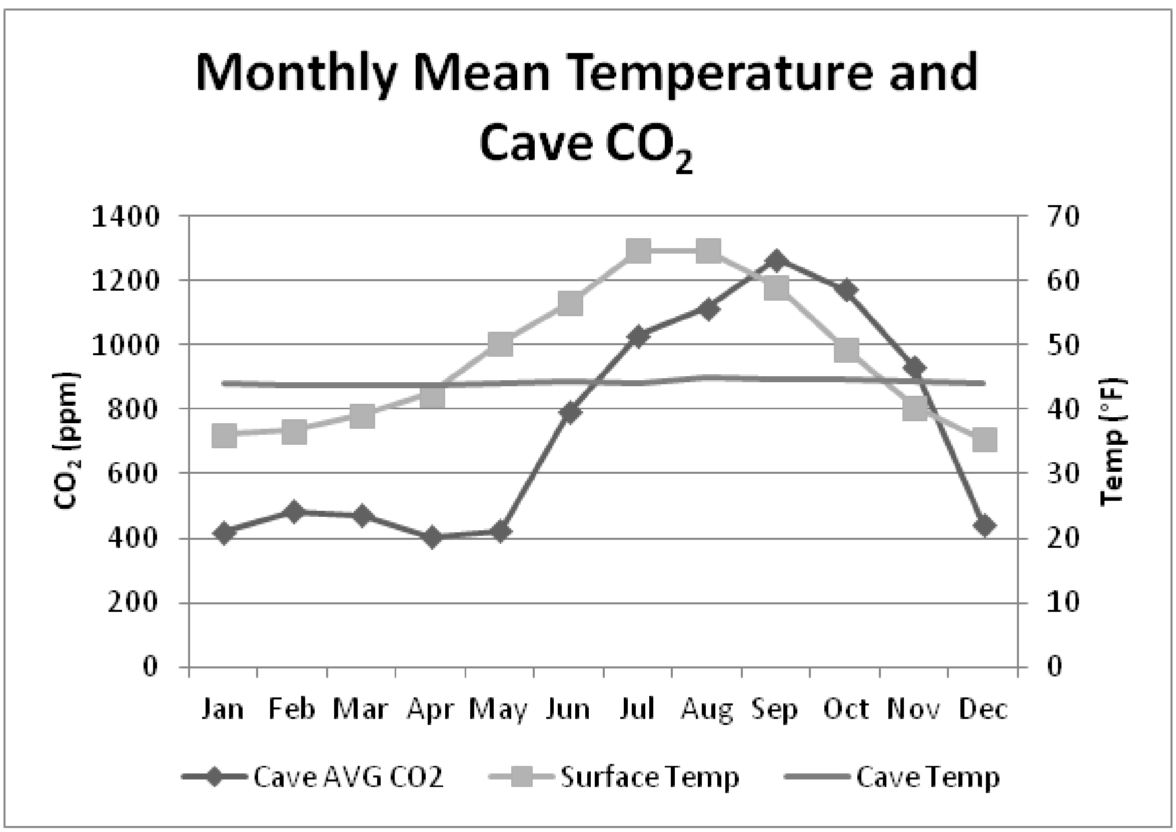

Figure 9. Cave ventilation regimes switch around April and November, when monthly mean surface temperature approaches cave temperature. This switch correlates with the buildup of CO2 starting in spring and the decrease in CO2 between November and December.

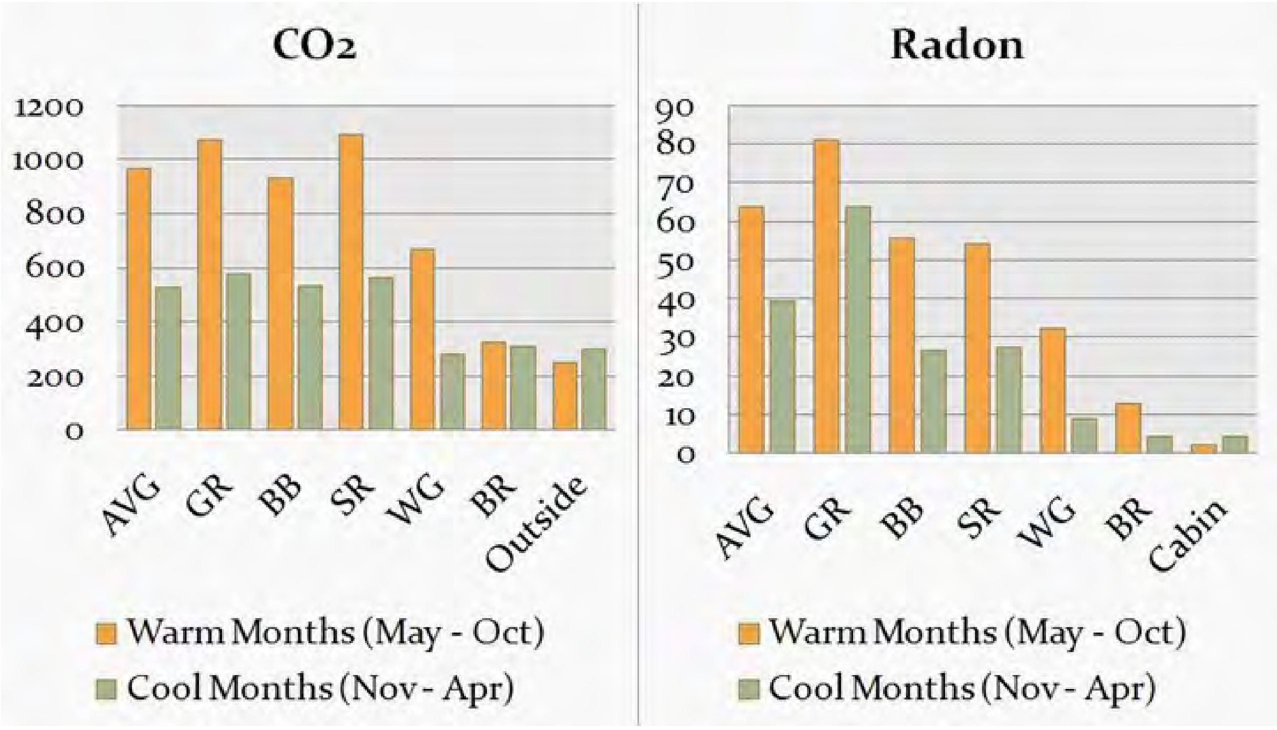

Figure 10. Baseline radon data in Oregon Caves were collected in three- and six-month periods in 2002-04 that corresponded with warm and cool months. Comparison of average warm- and cool-season CO2 and radon concentrations between sites, including control sites listed last on the graphs, supports the interpretation that airflow is the dominant control of seasonal variation. Relatively high radon in the Ghost Room (GR) in both warm and cool months was due to an outlier from winter 2003 being included in the average.

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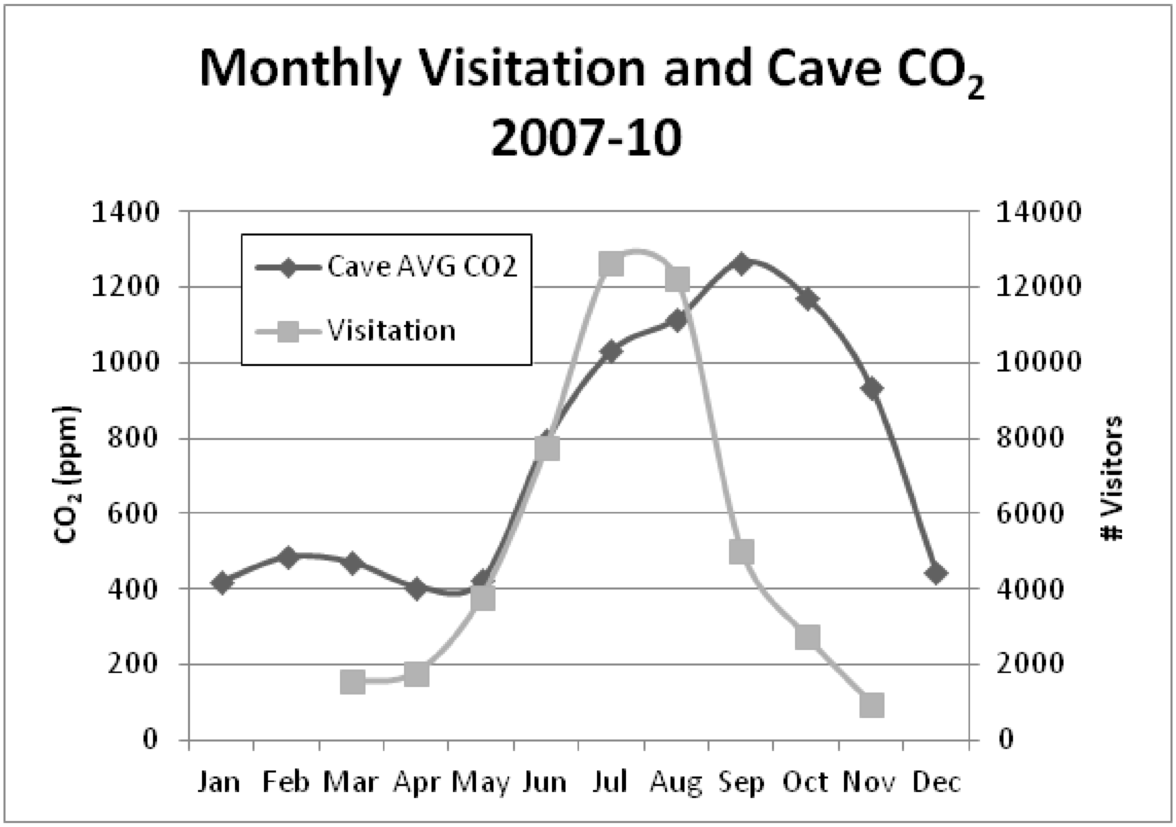

Figure 11. The seasonal variation of visitation coincides with the seasonal variation of CO2.

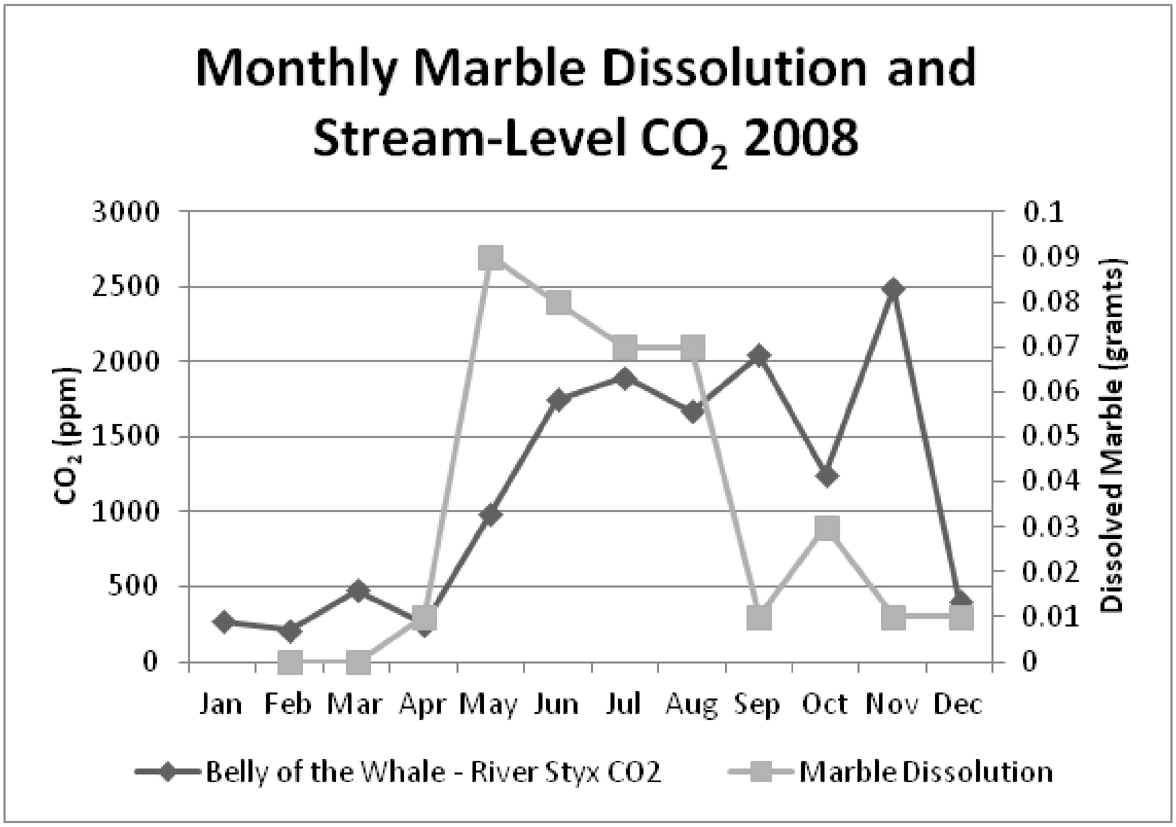

Figure 12. In a 2008-10 marble dissolution study, marble placed in Lower Cave River Styx dissolved seasonally (Hale, 2010). Both marble dissolution rates and CO2 seasonality may speak to cave stream processes, but how the two may be related is a matter for further investigation.

Studying Cave Visitation Trends

Jon Jasper
Outdoor Recreation Planner
BLM Arizona Strip Field Office
435-668-1325

Visitation data is vital information that can drive management changes for properly managing the use of caves. Visitation information collected, organized, and analyzed for the tours at Timpanogos Cave National Monument, uncontrolled visitation problems of the nearby Nutty Putty Cave, and pre and post gating of Bloomington Cave. There are many different techniques and benefits of gathering cave visitation data from tour tallies, cave registers, light sensors, and IR sensors.

Studying visitation is essential in cave management. It is as basic as surveying caves. Cave surveys answer basic questions such as "Where does the cave go?" and "How long is the cave?" Visitation studies can answer basic questions such as, "How many visits?", "When do people visit?", and "Who visits?" In the end, we do not manage caves. We manage the people's interaction with caves.

Why study cave visitation? We study visitation for these various reasons:

- to report total annual visitation
- to understand daily or seasonal use
- to evaluate effectiveness of closures and other policy changes
- to schedule monitoring for resource management or law enforcement
- to define problem use such as visits without permits or late night "parties"
- to collect basic demographics such as group affiliations, locations, age, etc.
- to develop group size and daily limits

Methods for collecting visitation

There are several ways to collect visitation data. Visitation data can be collected using data loggers, tallying up visits from tours or permitted use, or cave registers. Which method to use depends on the situation. Data loggers record time of visitation events. Data loggers can give accurate counts, but their use has high start-up costs and requires strict collection intervals. Cave registers are a simple method where visitors write down their visits. The use of cave registers is low costs, easy to implement, and low maintenance. Registers also can collect a variety of basic use information. Registers are a great way to start collecting visitation information and are an awesome tool for remote, seldom visited caves. Tallying tours or permits is great when available. Using tallies concurrently with other approaches can evaluate the effectiveness of tour scheduling or permit compliance.

Data Loggers

Data loggers have greatly improved over recent years. I have used three different types to collect visitor use data. They are TRAFx, TrailMaster, and Onset's HOBO Pendant.

Pros	Cons
• Lots of memory (about 2.5 years if sampling hourly)	• Expensive - $525 per unit
• Great battery life (3 years for 3 AA batteries)	• Short beam (10 feet)
• Easy to hide, lock up, or protect	• Passive IR (only one sensor)
• Also sells compatible vehicle counters and pressure pads	• Requires a Docking Module/Shuttle ($525)
• Can record by time stamp, hourly, or daily	

Table 1. Strengths and Weaknesses of TRAFx

Pros	Cons
• Long sensor range (150 feet) • Active IR sensor • Easy read out • Lower cost depending on amount of memory. Starts at $205 (2 KB) up to $460 (16 KB) • Is made for supporting wildlife cameras • Also sells a model for counting bats	• Short battery life of 4 months with 8 C-batteries • Only time stamp mode (can use up memory quickly) • Large, may be difficult to hide and protec • Requires StatPack software and cable ($150)

Table 2. Strengths and Weaknesses of TrailMaster

Each of these data loggers has their own set of strengths and weaknesses.

TRAFx (TRAFx.net)

TRAFx is a Canadian company whose products are designed to collect visitation data. They have two methods for counting visitation: passive infrared (IR) for counting visitation on trails and magnetic induction for counting vehicles, ATVs, or mountain bikes. Due to the long battery life and huge memory, TRAFx is becoming very popular for a complete system for collecting visitations among land management agencies.

TrailMaster (TrailMaster.com)

TrailMaster Infrared Trail Monitors were originally designed for triggering wildlife cameras. These infrared counters have both a transmitter and receiver (active IR) for higher precision. The two parts of the counter can be up to 150 feet apart, unlike the TRAFx IR counter's range of 10 feet.

Onset HOBO Pendant (onsetcomp.com)

Onset offers a huge suite of data loggers for resource management applications. The HOBO Temperature/Light Pendant has been used successfully for collecting visitation data within the total darkness of caves. Unlike the TRAFx or TrailMaster, the Pendant can be programmed to record the maximum light intensity readings over a user-defined time interval. In the darkness of a cave, any light reading above the ambient light can be considered a "visit." Unlike the other counters, the Pendant will be counting visits or groups rather than visitors.

Cave Registers

Cave registers are a simple method where visitors write down information about their visit. The standard method is using a notebook within the PVC pipe that is capped at one end with a screw off top on the other. It also can be as simple as inserting a notebook within a Nalgene bottle or army ammo can. Visitors can be encouraged by example to enter their names and date of visit.

Cave Registers are great for seldom-visited caves because few can resist the opportunity to leave their bit of history. Registers also work in highly-visited caves; however, they should be replaced often and located in places where groups can naturally gather. The register will slowly become a great replacement to tagging by providing an easy way to boast about visits.

Although registers do not provide time stamps or hourly visit records, they often can provide a glimpse on group sizes, group affiliation, where visitors are from, destinations in the cave, and comments on the cave's management (wildlife

Pros	Cons
• Long battery life – about 1 year • Waterproof to 30 meters • User defined sampling interval • Relatively inexpensive ($59 for 64 KB - $39 for 8 KB) • Also collects temperature readings • Compatible with HOBO products (mainly temperature sensors)	• Counts visitation by time periods • Not very sensitive - Must be directly in light's beam • Requires specialty batteries • Requires optic USB base station ($115) and HOBOware software ($99)

Table 3. Strengths and Weaknesses of HOBO Pendant

sightings, problems, water rise, etc). The gathering of this extra information can be greatly enhanced by using designed forms.

Unlike cutting and pasting electronically-gathered data, cave registers' data have to be manually entered. However, registers do not require batteries. They can sit collecting data for years and years. If registers are placed near the time of discovery, they can record and store the historical use of the cave.

Restricted Access Caves (Tours and Permitted Caves)

Usually every cave managed with restricted access in the form of tours or permits keeps records of all visits. Normally these records are simply tallied to report an annual visitation total. These visitation records can be used as a valuable management tool. They can be used to understand cave visitation trends. By studying the trends, you can answer questions such as: When is our peak visitation? When would be the best times to monitor? What is daily visitation? How we can best schedule tours?

Using the visitation data from permitted caves along with either data loggers or cave registers is a great way to evaluate management practices. Data loggers and even cave registers can record un-permitted use.

Access is restricted in caves with either high resource value or high recreation-use value. If the cave's access is being managed then more than likely other studies, such as bat counts, biological inventories, cultural resources, environmental monitoring, and water quality, are also being conducted. Visitation can be a factor affecting many of these resources.

Caves have a very limited carrying capacity. The carrying capacity depends mainly on group size and the frequency of group visits. Basically, what is the largest size group that can fit and be controlled into the smallest spot of the cave and at what point do other problems (sound, crowd control, temperature, etc.) start occurring? When the carrying capacity is exceeded, the amount of resource degradation will dramatically increase.

Many employees of tourist caves believe their tours are overcrowded or exceed their carrying capacity. In a pilot study at Timpanogos Cave National Monument, staff collected the number of resource protection and safety violations to compare with tour size. We expected that violations per tour would dramatically increase when the tour size exceeded its carrying capacity. With a strong tour cap in effect, the study did not get enough range of tour sizes to test our hypothesis.

Conclusions

Cave visitation can be collected in three ways: data loggers, cave registers, and tallies from permits and cave tours. Data loggers are a great method to collect detailed data on cave visits. Cave registers are a cheap, low-tech method to collect visitation counts, demographic, and basic comments, especially in seldom-visited caves. At restricted access caves, visitation studies can be a great tool to show the effect of visits on other resources (biology, environment, water quality, etc.) and to guide and to evaluate management actions.

Visitation is one aspect of cave management that is greatly overlooked. Hopefully, more organizations will help in developing how to incorporate studying visitation into mainstream cave management practices.

The PowerPoint presentation can be viewed at: http://jonjasper.com/Presentations/CaveVisitation/

Comparison of Cave Gate Materials

Jim Kennedy, Conservation Biologist
Habitat Protection Coordinator
Bat Conservation International
Post Office Box 162603
Austin, TX 78716-2603
jkennedy@batcon.org
512-327-9721

Abstract

Many types of steel have been used over the years in building cave gates, including ¾" and 1" rebar; 1" mangalloy hardened steel bars; 3"x4" rectangular tubular bars; 2", 3", and 4" angle iron bars; and stainless steel tubular and angle iron bars There are pros and cons to each type. We compare and discuss each material, focusing on cost, weight, availability, ease of use, and most importantly, strength and cross-sectional restriction of flight space. The horizontal 4" angle iron bars (with stiffeners) long been recommended by the American Cave Conservation Association and Bat Conservation International have clear advantages to the alternatives. Designs using these materials have become the default "industry standard" for bat gates, and are widely accepted by the U. S. Fish and Wildlife Service, the National Park Service, the U. S. Forest Service, the Bureau of Land Management, The Nature Conservancy, The National Speleological Society, and other major cave management entities.

What Are We Trying to Protect?

Cave gates are designed to protect the contents of the cave (Kennedy 2006). If the gate is weak and people can get in the cave, then it is not doing a good job of protection. Likewise, if the gate modifies the natural processes of the cave by altering airflow and changing the internal microclimate, impeding the flow of water and nutrients into the cave, or restricting the movement of animals into or out of the cave, then it may be detrimental despite the good intentions behind its installation. A good gate must be both secure and biologically transparent (Currie 2002, Elliott 2006, Nieland 2004, Tuttle 1977).

CHARACTERISTICS OF A GOOD GATE

- Strong and Secure
- Environmentally friendly
- Long lasting
- Relatively easy and inexpensive to build
- Rescue/Research friendly
- Protects ALL cave resources

What is a Bat Gate, and Why Should We Use It?

"Bat Gates" are gates that are bat-friendly, meaning that they allow for free flight of bats through the gate (Powers 1985, 1993). They typically consist largely of horizontal bars, with few, widely-spaced, vertical bars (Dalton 2004). Because bats do not negotiate closely-spaced vertical elements very well, but can easily fly through horizontal elements, the spacing and placement of vertical supports must be carefully considered. The larger the resident bat colony and the higher the level of activity (such as at a maternity cave, where there are daily emergences), the more important this requirement becomes (Powers 1996). Horizontal bars should be spaced 5 ¾" from the top of one bar to the bottom of the bar above it. This requirement may be slightly modified with closer bar spacing at the bottom only on gates placed in high traffic areas where small children or pets may be tempted to squeeze through the bar openings. But the top ⅔ of any gate area should always provide maximum flight space.

Grid-type gates, including cable netting, should never be used for openings with even moderate bat traffic. They are recommended mainly for vertical openings necessary to maintain airflow into complex systems with few (if any) emerging bats, such as large, multi-level abandoned mines (Kretzmann 2004a).

Bat gates also should NEVER be built in passage restrictions, or areas with tight turns. In addition to being a possible detriment to bats, gates built in constricted areas have a much greater chance of altering airflow and microclimate. If the entrance is vertical, especially if it is a small opening, then the gate needs to be raised above the surface to give bats adequate flight space and allow predator avoidance. Cupola-style gates are recommended in this situation (Kretzmann 2004b). The bottom line is that you need to know something about the current and historic use of bats at the cave before designing the gate.

Even if the cave is not a "bat cave" and never has been, bat gates are still the preferred closure method to protect other cave resources present (Olson 2004). The only exception may be if the cave was dug into and it is important to maintain air-lock conditions to isolate surface fauna from the cave, prevent drying, or microbial contamination of a pristine environment. Gates are also impractical for extremely large vertical openings, which can only be protected by fencing.

There are many other aspects of bat gate design and construction that are beyond the scope of this paper. For difficult entrances and non-standard situations, please feel free to contact Bat Conservation International for advice.

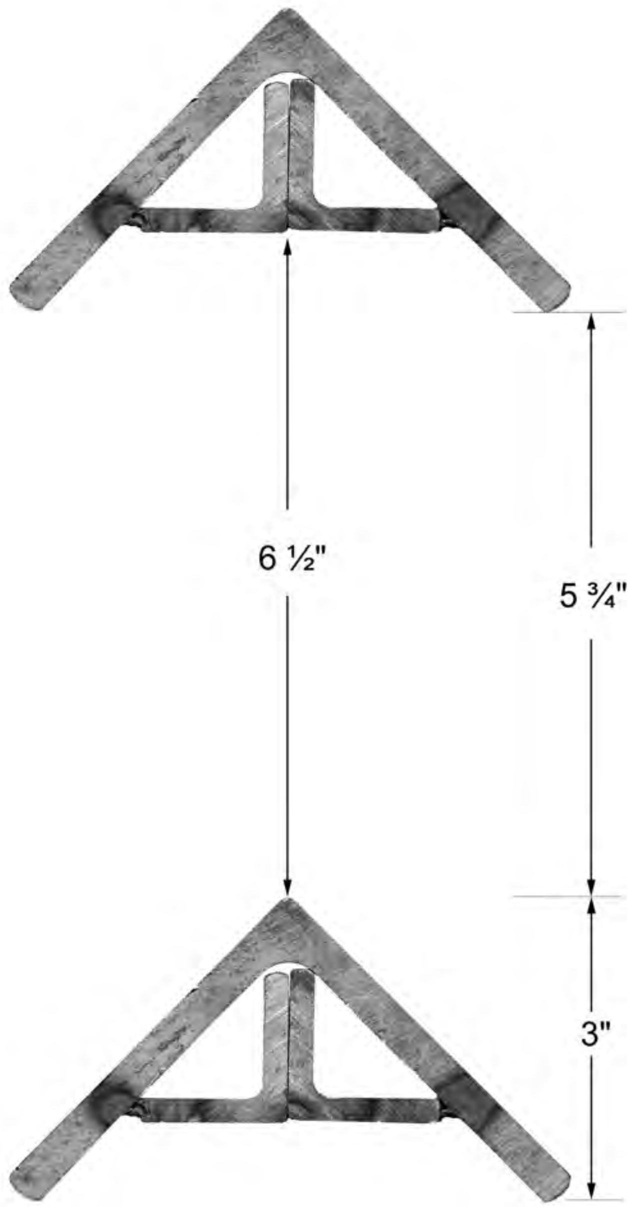

Figure 1. Angle-iron bars, even with the standard 5!” spacing between bars, provides maximum flight space for bats due to the recessed stiffeners.

Material Types

Material selection for bat gates usually is based on several factors: strength, weight, cost, and availability. Occasionally there are special conditions, such as corrosive environments or aesthetics, which require special materials such as stainless steel. But those situations are rare, and so-called “mild” (as opposed to hardened or tempered) steel is the best choice in the vast majority of cases.

There are many types of materials currently used for cave and mine gates. These include round bar (ranging from ¾” rebar to 1” hardened mangalloy); pipe; 2–4” angle iron, with and without stiffeners; and rectangular tubing ranging from 2”x4”, 3”x4”, 3”x3”, and so on. Each material has pros and cons, but certain shapes (especially round bars and pipe) are inherently weak and easily bent. Some (like rectangular tubing) take up more potential flight space. Others may be difficult to obtain locally, have a higher per-unit weight (an important consideration when materials must be airlifted to the site), or may not be manufactured domestically (mangalloy). Odd materials, such as I-beams and others, may be components of large gates, but should never be considered a primary material for gate construction.

Rebar and Other Similar Solid Mild Steel Round Bar Stock

Rebar, short for concrete reinforcing bar, is readily available and very inexpensive. At the time of this writing, the market price for 1” (#8) rebar was approximately $3.81 per foot. It is lightweight (2.67 pounds per foot), but notoriously weak, being composed of low-grade metals and designed to be imbedded in concrete. By itself, it is easily bent, or cut with a common hacksaw, making it very vandal-prone when used as a gating material. The lack of strength necessitates forming the rebar into a grid-like pattern for gate construction, which may be suitable for sites with only a handful of bats, but very detrimental to larger colonies due to the large number of vertical supports required. Finally, the curved surface of the material makes for very small and weak welds when attached to the curved surface of other rebar pieces.

Pipe and Other Hollow Round Stock

Many budget gate builders turn to surplus steel in gate construction, including steel pipe. Pipe has all the disadvantages of rebar and other solid round mild steel stock. It can easily be bent and cut, and is difficult to make strong welds on the round surfaces. To offset the weakness, some builders insert loose rolling bars inside the pipe, such as rebar, before welding in place. Others fill the tubes with concrete, but the time and difficulty offset any cost savings.

Rectangular and Square Tubing

Rectangular tubing comes in a wide variety of dimensions and thicknesses, making it one of the most versatile materials available for cave and mine gating. It is strong, and its flat sides allow for long, strong welds. Some gate builders have even inserted other materials (such as loose rebar, or even concrete) into the hollow center of the tubes to hinder vandals who attempt to cut through the bars. It is slightly heavier on a per-piece basis than a similar-sized piece of angle iron (10.51 pounds per foot for 3”x4”x¼” rectangular steel tubing) and more expensive ($11.77 per foot)(source: metalsdepot.com). It works particularly well for small openings with low risk of vandalism (Vittetoe 2004). The chief drawback is that it restricts available flight space more than any other material, even angle iron with stiffeners.

Angle Iron with Stiffeners

Angle iron is also readily available in a variety of dimensions and thicknesses. By itself, it is relatively weak, but can be made extremely strong with two pieces of smaller angle iron welded inside the apex, as stiffeners. However,

Figure 2. Rebar gate on gray bat maternity cave. Note closely spaced vertical supports. This cave was abandoned by the bats shortly after the gate was installed. It has since been replaced witha more bat-friendly design. Photo by Bill Elliott.

this does increase the amount of materials, weight, overall project cost, and construction time. For comparison (see 3″x4″x¼″ tubing above), 4″x4″x⅜″ angle iron weighs 9.80 pounds per foot and costs $8.92 per foot (source: metalsdepot.com). With two 1½″x1½″x¼″ angle-iron stiffeners inside, the total weight increases to 14.48 pounds per foot and the cost increases to $12.96 per foot. The primary benefits, however, are increased flight space between bars (even at the same 5¾″ spacing), sloping surfaces that are less disruptive of airflow, stronger overall bar strength (more important for wide gates), and more material mass which increases difficulty of cutting by vandals (Powers 2004). Small diameter rebar can also be inserted inside the stiffeners to provide an additional barrier to cutting.

Figure 3. Rectangular tube steel gate on an abandoned mine in Arizona. Photo by Jerry Fant.

Hard Facing

All standard steel materials can all

Figure 4. Constructing an angle-iron bat gate, with stiffeners. Photo © Jim Kennedy, BCI.

have hard facing added, which is a special, high-manganese welding rod that provides a cut-resistant layer to the bars. Unfortunately for cave gate builders, the easy availability of demolition saws and cutting torches from equipment rental companies means that no cave gate is truly vandal proof.

Mangalloy

Mangalloy is a specialty steel that has a high manganese content, much like the hard-facing welding rods. Manganal® is one common brand. It is most commonly used in jail bars, tool tips (such as the edges of bulldozer blades), and mine rails. It is extremely wear-resistant, and is much harder to cut or grind. It comes in solid round, solid square (up to 2"), and angle (up to 2") stock. It is more expensive than any other material type previously mentioned, usually about 3 times the cost of similar-sized angle iron or rectangular tubing, and it doesn't come in large sizes. Weight is similar to mild steel. It requires special welding rods for construction, but can still be cut with a torch. It is no longer made in the USA (due to the toxic nature of the manufacturing process), which may be a concern for projects involving federal funding. Because of its smaller overall dimensions, it can still be easily bent, requiring more closely spaced (and less bat friendly) vertical supports. Gates made with this material can also more difficult to repair by non-specialists, due to the welding rods required (Werker 2004).

Stainless Steel

Stainless (high chromium) steel is used in areas with corrosive environments, such as certain bedrocks, or mines with acid drainage. Its strength and weight are comparable to regular steel. It is occasionally used in areas where aesthetics are a major concern. It comes in many sizes and shapes, but is extremely expensive ($39.20 per foot for 4"x4"x⅜" angle stock). It also requires special welding rods for construction and repairs, and is difficult to fabricate in the field (Werker 2004).

Other Gate Materials and Options Not Covered in This Paper

There are many other materials and gate designs in use that are not covered by this paper, but which may be perfectly acceptable in certain situations. These include the new concrete and steel hybrid gates that are used where vandals repeatedly steal ordinary gates to sell for scrap metal, lattice gates and grates (including cable net closures), and hybrid lattice and bar combination gates. Cave and mine gate designs continually evolve, so it is best to have current training or work with a highly experienced and knowledgeable expert when tackling a new project (Kennedy 2004). For more information on these materials and designs, or assistance in gating projects, contact Bat Conservation International.

Summary

While cave and mine gates have been built with a wide range of materials in the past, some clearly are superior for strength, weight, availability, ease of working, cost, and environmental friendliness. Our recommendations are primarily for 4”x4”x⅜” mild steel angle iron with two 1½”x1½”x¼” mild steel angle-iron stiffeners welded inside. For narrow openings (such as found at many abandoned mines) and less vandal-prone sites, 3”x4” rectangular tubing may be an acceptable substitute, especially if cost is a factor. We strongly discourage the use of pipe, rebar or other round stock, and feel that specialty steels such as mangalloy and stainless steel should only be used in very specific circumstances.

Figure 5. Mangalloy cave gate in Utah. Note how bars have been bent to illegally gain access, necessitating temporary repairs. Photos © Jim Kennedy, BCI.

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Spanish Moss Cave - A 34 Year Photo Comparison Project

Michael Leavitt & Adam Leavitt

Abstract

In 1976, 78 photos featuring cave formations in Utah's popular Spanish Moss Cave were taken and then given to the Timpanogos Grotto. In 2010, they re-surfaced and with the help of his father, Adam Leavitt created and managed his Eagle Scout project designed to recreate the 78 photos in to compare differences within the cave. The result is an online specialty website featuring the project, photos and findings. Spanish Moss Cave sits on Forest Service land and has been gated and its access managed by the local grotto since the late 1970's. This project has helped in determining the effectiveness of the management plan.

How Resilient to Climate Change is a Show Cave at Oregon Caves National Monument?

Emily Ring
19000 Caves Highway
Oregon Caves National Monument
Cave Junction, OR 97523
1.541.592.2100 x 2254
emily_ring@nps.gov

John Roth
19000 Caves Highway
Oregon Caves National Monument
Cave Junction, OR 97523
1.541.592.2100 x 2230
john_e_roth@nps.gov

Abstract

Increased vegetative competition from fire suppression and higher evaporative climate conditions may be accelerating the cave ecosystem's re-entry to a low carbon input comparable to the driest part of the Holocene. A further decline of organic carbon from this point may raise extinction rates that are normally low in caves. Initial comparisons of recent organic carbon input into Oregon Caves with high resolution paleoclimate data from the last 330,000 years helped to quantify an increased extinction rate threshold for the caves. Water samples from a wet (1992-1993) and a dry cycle (2010-2011) were analyzed for total organic carbon (TOC), conductivity (σ) and chloride (Cl) from 7 subsurface sites and 2 surface sites. The project suggests what mitigation strategies might be inherent to the cave system itself, as well as measures available to future management.

Keywords TOC, Oregon Caves, drought, resiliency, fire, fuels reduction, geohydrology

Introduction

The cave system at Oregon Caves National Monument (ORCA) lies within the Applegate geologic group of volcanics with slate, quartzite, chert, limestone and marble lenses (Briles *et al.* 2005). The age of the marble has been estimated at 250 Ma and is largely a solution cave formed in a faulted and folded marble, dissolved out by surface waters that have percolated through soils or other sediments. Elevation ranges from 1220 m at the lowest entrance to about 1500 m at the main cave exit.

Previous hydrologic studies indicate that most water enters the cave through fissures and dome-pits and to a lesser degree by stream piracy (Briles 2003). Precipitation entering the cave takes hours to days to reach the upper part of the cave. Movement of water through surface soils and into the caves is expectantly complex. Multiple factors contribute to variability in total organic carbon (TOC), chloride (Cl) and conductivity (σ) including factors that affect the amount and connectivity of surface to subsurface water (soil density, structure, barrier potential, precipitation), aggregation (cementing agents like clay and organic matter, soil structure), elements in soil water (salinity, exchangeable ions, soil water content, temperature), and the conductivity of the mineral phases (types and quantity of minerals, timing of exchange and measurement, ions).

This project focused on the intersecting factors of fire or fuels reduction and climate change within our system's larger complexity. Project conclusions were supported by preliminary drip rate and σ data analysis, as well as likely microbial response to stressors as evidenced by TOC patterns within the cave system.

In the Klamath-Siskiyou bioregion where ORCA is located, ecosystems have been formed by disturbance events and species seeking refugia during times of historic continental change. In particular, disturbance by fire has been the driving creator of natural heterogeneity in our region that was recently (within the last century) suppressed. In absence of fire's beneficial role, droughts may be continuing to play a role that has potential benefits. In essence, a drought is also a disturbance event of significant spatial extent and, as a disturbance, increases spatial and temporal heterogeneity. Like fire, its disturbances break connectivity and the homogeneity that can diminish biodiversity over time (McGinness and Arthur 2011). Moderate surface disturbances increase biodiversity by reducing competition but such effects are likely to be more muted underground. Also, like fire, disruption of ecosystem connections by a drought cannot be too severe or for too long a period, lest the potential benefits become detrimental to the system.

Under this scenario, we looked at potential impacts from the 1980-1993 drought or dry cycle. This cycle was punctuated by rainfall relief every several years that did not break the drought, and then broken in 1993-1994 by significant but not overly monsoon-like precipitation. The graduated reintroduction of normal to above-normal rainfall likely allowed for mitigation of long-term drought damage. Concurrently, we looked at preliminary results from ORCA's fuels reduction. Early monitoring indicates that hand piling and burning following thinning activity have been moderate enough to create temporary subsurface signatures (+/- 1 to 2 yr post treatment) in some sites but did not create any long lasting hydrologic signatures (> 2 yr post treatment).

Project Objectives

The project was formed to address the following questions:

1. What differences, if any, are there between the cave water chemistry dataset from dry years and the data-set from wet years?

2. What measurable impact, if any, can we see being caused by fuels reduction activity currently taking place above the caves?

3. What can be learned from the change in TOC over time and the implications, if any, for potential survival or starvation threshold scenarios within the cave eco-system?

4. How might these results inform resource manage-ment about actions to take or not take under an order of potential climatic scenarios?

Context for Thresholds

Historic Climate in the Southwest Oregon Region

An ORCA speleothem-based temperature reconstruction indicates the past 9000 (9 Ka) years of regional climate was characterized by a general warming trend, consistent with an increase in winter insolation at 45°N (Ersek *et al.* 2006). The Medieval Warm Period (~800 to 1300 AD) in southwestern Oregon was characterized by two warm wet periods interrupted by a cooler dry period. The most recent droughts in this record were described between 4 Ka and 1 Ka.

ENSO, or El Niño/Southern Oscillation, conditions were suppressed during the middle Holocene ~8 Ka and 4 Ka while the Northeastern Pacific remained in a generally more negative PDO, or Pacific Decadal Oscillation, phase. This resulted in a generally wet Pacific Northwest with droughty interior West and Southwest (Tripati *et al.* 2009).

ORCA speleothems further indicate local glacial periods were mostly characterized by non-deposition and little or no dissolution in the caves. Potential causes for minimal growth periods include the presence of longer annual periods of frozen soils above the cave preventing water infiltration, decreases in precipitation, changes in soil CO_2, and temporary flooding events (Ersek *et al.* 2006).

A prolonged warm dry period in Oregon, Washington, and the Klamath Mountains of northwestern California apparently terminated around 4300 AD by the onset of cooler wetter conditions (Briles 2003). This ended region-wide multi-centennial drought cycles (>200 yr) being locally expressed at decadal to multi-decadal extremes and pattern interruptions or climatic variations of 2-5 year frequencies.

A paleoenvironmental study by Rushdi *et al.* (2009) on aliphatic lipids at ORCA indicated higher organics in the caves during speleothem deposition during the Pleistocene droughts and suggested this may also have inhibited calcite deposition during those periods. The estimated percentage of microbial inputs ranged from 42 to 90% of the total subsurface lipids and also showed an increase in flux during warmest (interglacial) climates. Rushdi (2009) suggests either a greater source of organic materials were being received or stored during interglacial times, and/or greater efficiency of compound capture was occurring during rapid calcite growth.

When taken together, sources of information such as these indicated that ~ 4 Ka-4.3 Ka AD may provide our best available model for a modern survival threshold scenario inside the caves.

Potential New Climate as Projected for the Region

Interpretation of past climate data can only generate projections for specific assumptions. Assumptions should fall within the range of what might be reasonable to expect, but the future can still end outside the range of expected scenarios. This is especially true presently, as there are now fewer analogies with past paleoclimates. One example of this is atmospheric carbon dioxide that may be higher at present than at any time in the past 15 Ma (Tripati *et al.* 2009). That being said, the current regional climatic projections are:

- Weak ENSO/strong negative PDO impacts for next 10-30 year cycle
- Reduced North Atlantic thermal-haline circulation
- Changing atmospheric composition and feedbacks
- Shift from decadal to inter-annual frequency patterns
- Regionally increased rainfall but decreased snowpack, earlier springs, extended summer-to-fall drought sea-son, colder wetter winters

Current hydrologic conditions cannot be assumed to represent ecological or historical norms, without risk of substantial error. The 30-year hydrologic span of this project has incomplete data gaps and would require longer and more detailed records to improve understanding.

Methods

During the years 1992-1993, the following sets of data were collected: pH, water temperature, total dissolved solids (TDS), atmospheric carbon dioxide (CO2), alkalinity, TOC, magnesium (Mg), sulfate (SO_4), Cl, sodium (Na), iron (Fe), zinc (Zn), and calcium carbonate ($CaCO_3$).

During 2010-2011 the following sets of data were collected: TOC, Cl, TDS, pH, and water temperature.

For context, the dry years in this project are characterized as having received <20 inches or less than the annual average rainfall of 62 inches.

During the foundation of the analysis spring rain collections, subsurface drip rates, a biological oxygen demand study, local precipitation gages, annual stream flow and microbial metabolism studies were also evaluated for their relevance to the project's focus.

In 2010-2011, lab analysis of chloride was arranged with Grants Pass Water Lab. Testing graduated from a 1.0 filter (considered too coarse except in heavy winter and spring flows) toward a 0.5 filter with a D5085 standard determinant method. Lab analysis of TOC was provided in partnership with Dr. John Salinas of Rogue Community College using a 1.0 mg/L baseline and a non-particulate organic carbon (NPOC) sparging acidification method.

Collections were provided by ORCA staff and a volunteer Southern Oregon University (SOU) student. The 2010-2011 samples were meant to replicate the 1992 collections as closely as possible. Rounds were completed bi-monthly and are expected to continue through the 2012 fiscal year. Sample bottles were standard 250 ml Nalgene. They are kept chilled and transported for analysis within 24 hours from the field.

In our analysis, TOC should be understood to mean the sum of dissolved organic carbon (DOC) in solution with particulate organic carbon (POC). Water studies may discuss DOC concentrations, but rarely report TOC, and those that do almost always focus on pollution applications. Because organic carbon is vital to supporting microbial life at Oregon Caves, an understanding of TOC within our system was considered necessary in evaluating aspects of health and resiliency.

Locations

Sampling in both 1992-1993 and 2010-2011 visited the following subsurface and surface sites:

- River Styx: a lower cave stream which is a mixture of diffuse and discrete waters
- Imagination Room pool: diffuse origins from a crack
- Lake Michigan: a diffuse pool
- Shower Room: a discrete dome drip
- Ghost River Styx: a discrete upper cave stream
- Ghost Room: a discrete dome drip
- Wedding Cake: a diffuse bedding plane drip
- Upper Cave Creek: a surface stream pirated, but not swallowed, by the cave

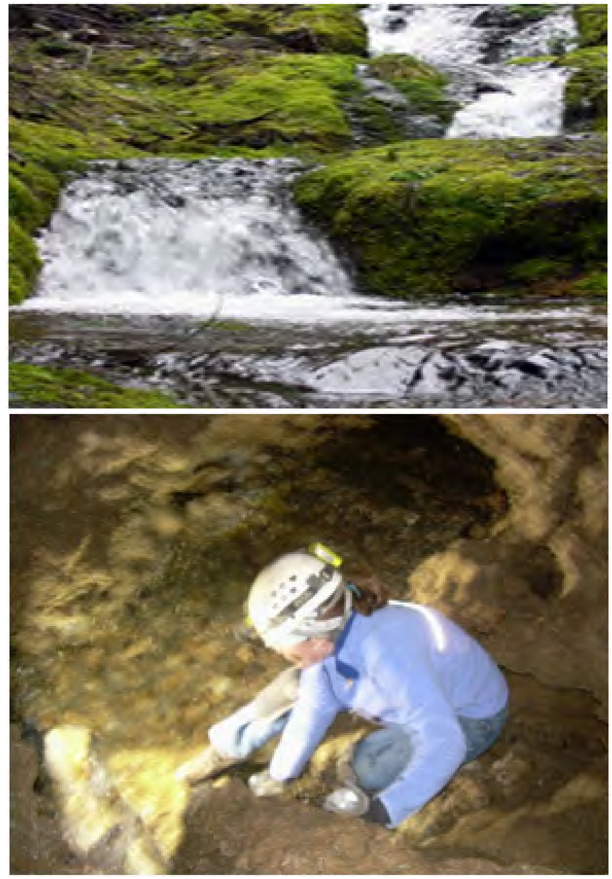

Figure 1. Image of surface stream and subsurface stream sample collection sites.

- Lower Cave Creek: a surface stream re-emerging from the cave

Summary of Results

- TOC evidenced an initial decline in 1989-1990. It then rose and steadied, temporarily fluctuated end of 1992 to early 1993 (concurrent with a large rainfall event) yet otherwise held fairly constant throughout the dry cycle.
- 2010-2011 TOC consistently lower than 1992-1993 levels, perhaps due to dilution from greater atmospheric deposition and increased volumes of flow.
- Dilution and flushing factors seemed insufficient to explain differences between datasets.
- Surface TOC differences between datasets were within expected ranges, but were outside the expected ranges for Cl and σ was slightly higher and more variable in 2010-2011 than 1992-1993, as was expected.
- σ values increased late summer to early winter, before accumulated impact of winter precipitation, when water is most alkaline and less supersaturated in calcite. σ decreases coincided with decreased drip water flow. Minimal values were during spring; perhaps due to dilution and/or the removal of carbonate ions due to precipitation of calcite.
- Cave biofilms might have received a short-term

benefit from drought years (initial food surplus due to no flushing events) but longer TOC stability may be due in part to microbial starvation mode abilities that reduced consumption needs.

- Overall results support an earlier study's proposal that the source waters for Shower Room and Ghost River Styx may be from other surface waters as yet unidentified by previous dye traces.
- Evidence that Wedding Cake drip is more closely tied to the surface with a different source than previously proposed.
- Ghost Room drip evidencing three to four month lag time with a different source than previously proposed.
- River Styx closely mimics the Upper Cave Creek for all three variables, as was expected.
- Composition of the samples from Lake Michigan and Imagination Room indicate similar source water with similar travel histories.

- In most sites for 2010-2011, TOC spikes and Cl drops in July, which appears to be the signature in change from the stream recharging to the aquifer recharging.

Discussion

Both datasets evidence the arrival of recent water in spring and summer by an increase of TOC values. Discharge of long residence time water over low flow dates was often characterized by a slight decrease of TOC. Greater depletions of TOC are temporarily occurring in the system during and after a substantial flow event.

Both datasets also support the idea that the underground system mimics the surface system in terms of conduit switching due to hydraulic head pressure changes, allowing cascading stages of ground and stream recharge followed by lower aquifer zones.

The project confirms that ORCA's karst groundwater nature of ORCA are usually "circumneutral" (around neutral pH of 7.0) and fall in the 6.7 to 8.0 range. The pH results of 7.55 – 7.89 found in a few subsurface samples from years 2010-2011 are in the high end of a normal range. This may be due to active biological (bacteria mostly) transformation activity, causing reactions to temporarily fluctuate water pH into range extremes. The older dataset had even higher ranging pH values (from 8.46-9.30). This may be due to microbial acidification and ammonification of sediments in response to the prolonged drought and consequential changes of biomass activity.

Unexpected was the consistently higher conductivity or TDS readings for Lower Cave Creek (values range 20-16) than for Upper Cave Creek (values range 08-14) during 2010-2011. In 1992-1993, Lower Cave Creek was not included as a sample site. Upper Cave Creek values range during that time period was 08-16. Higher Lower Cave Creek ranges seen in 2010-2011 may be attributed to the fact that it receives groundwater input, and therefore greater inorganic dissolved solids, than the Upper portion. Consequently, the groundwater it receives as it exits the cave carries a consistent signature of higher conductance. It remains unknown what concentration of high conductance could become damaging to freshwater species downstream, and whether human use of the Chateau or the Caves, or both, are contributing to the higher signature.

Otherwise, conductivity for both dry years and wet years were as expected, given the positive relationship of surface conductance to soil moisture. Temporal variability across both datasets reflect ongoing site-specific changes associated with differing environmental conditions. Overall, however, the conductance and chloride values were lower and less variable during the drought years than in the more recent wetter years; a temporal pattern not unexpected.

Since organic carbon availability is a controlling factor for subsurface biologic activity, these project results suggest that short-term variable drought conditions (<12 yr) may not endanger *certain* biota. It may even temporarily stimulate microbial nutrient retention. However, prolonged and severe drought (>12 years) might begin true starvation conditions, given our current estimated biotic populations.

When adding in the results from initial fuels reduction activity, potential resource management implications begin to emerge. For example, given the lag time between surface and subsurface conditions, a management fuels reduction action would have to be required by year 10 or 11, in order to potentially mitigate a detrimental impact by year 12 or 13 of a decadal drought cycle.

Drip-rate buckets monitoring infiltration into cave sites

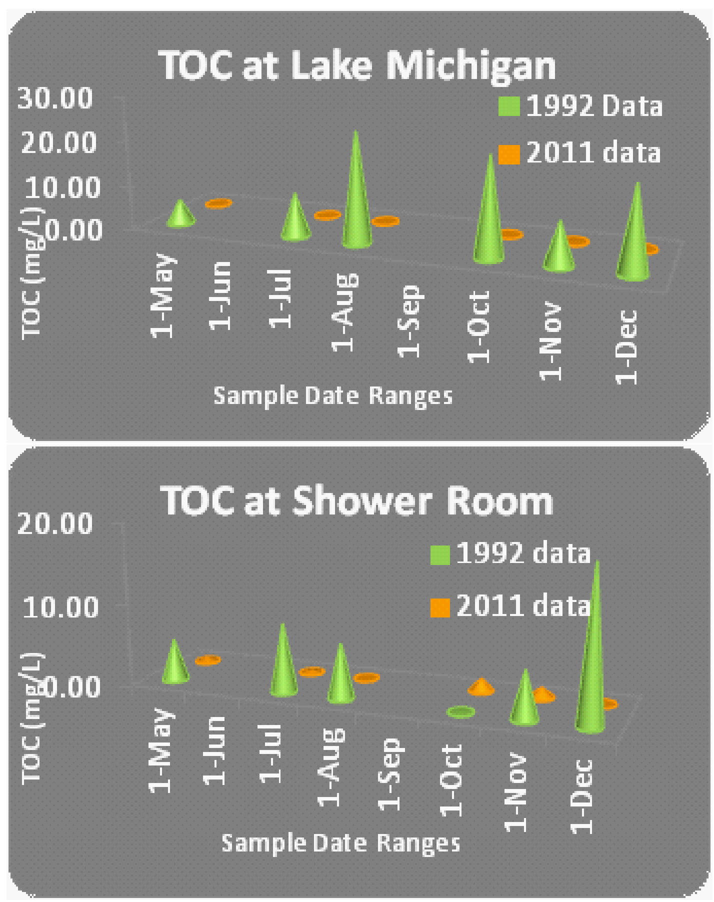

Figure 2. Total organic carbon concentration comparisons at two subsurface sites. This graph is typical of concentration patterns found across subsurface sample sites.

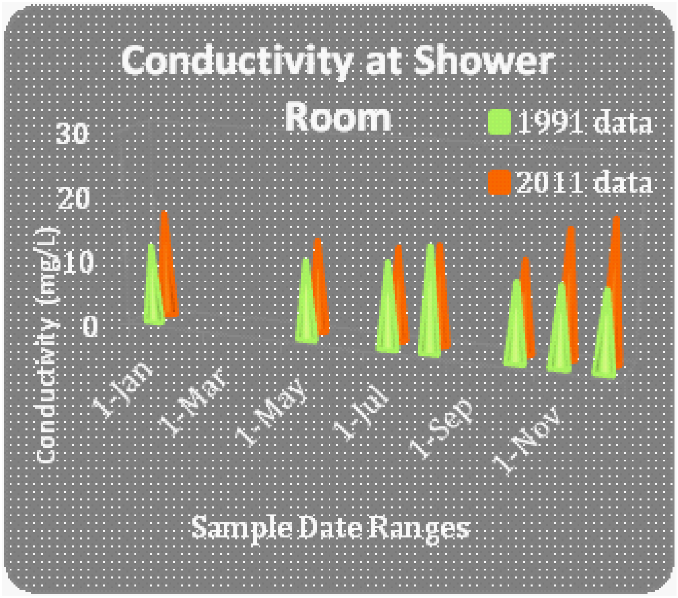

Figure 3. Chloride concentration comparison at a subsurface site typical of concentration patterns across sample sites.

from the surface did reveal influx rate changes (increased drips per minute) at sites thought to be closely tied to surface sourced water. Changes have yet to be seen at sites of indeterminate lag times and subsurface fissure sources. Future analysis incorporating 2009 - 2011 drip rates with precipitation and calculated dilution factors should provide more in-depth results.

Data from the fuels plots showed increases of organic carbon infiltration in year 1 and 2 of post-treatment growth. These were thinning plus burn treatments. Different results from mechanical-only or burn-only were found in the literature review. The literature review also suggests an eventual decline in water and carbon following any post-treatment growth spike, due to remaining vegetation increasing their storage capacity and compensating for expanded nutrient availability (Stanturf 2002; Wilson *et al.* 2002). Additional subsurface TOC and drip-rate monitoring through 2012 should help to determine what trends are evident at ORCA and how they relate to overhead locations of ORCA fuels plots.

Microorganisms Role

During drought, TOC - particularly DOC concentrations - have the potential to increase in soils. Yet the concentrations in surface streams and surface runoff may decrease due to low water levels with an inability to mobilize or transport TOC. Consequently, we expected decreased organic carbon signatures to be more evident in the cave system during dry years than wet. The preliminary results of this project suggest more nuanced relationships.

In the sediment beds of water sources that feed our cave system, different changes would have occurred during different stages of the drought cycle. In the early stages of drying, the sediments and soils may have been two-layered, an oxic or aerobic layer above an anoxic or oxygen depleted layer, as is common for freshwater streams (Larned *et al.* 2006). Since nitrogen metabolism is largely a function of bacterial activity, in the early stages of drying in the top oxic layer, mineralization would occur along with nitrification. Eventually, ammonification can occur in the anoxic layer. As the oxic layer deepens, the microbiota may experience temporary population surges, proliferating and breaking down organic matter. As the anoxic layer retreats and the drought goes on over time, a shutdown of microbial activity may occur, reducing denitrification. Further desiccation from drying would greatly reduce microbial biomass in the surface, with their mortality contributing to concentrations in the dry sediments (Carter *et al.* 2002).

We saw initial increases of subsurface TOC subsurface following the drought's early years. This might be due to retention of organic carbon in the cave system because no flushing was occurring. In other words, there were no large water volumes to remove organics from the system during flow events (Simon *et al.* 2007).

A temporary surge in ORCA cave microbial populations may have occurred subsurface, mimicking the surface trends, although at a time lag and across a longer time span. Mild surface acidification would have lead to temporary reductions of TOC values (Wilson *et al*. 2002). This may have been evidenced in data analysis where we see temporary, rapid subsurface decreases in TOC coinciding with rainfall events that were not sufficient to break the drought, but were able to penetrate anoxic layers.

Oregon Caves exhibits microbial diversity in its streams and surfaces – moon milk, cave slime and biofilms, microbial mats, diatom-covered stream cobbles and cyanobacteria in marble. We focused on biofilms and their potential role in a cave's response to external pressures. Biofilms are microorganisms from various taxonomic groups that assemble together for mutual benefit and niche overlap. They can consist of bacteria, microalgae, micro-mycetes and others. They provide beneficial or harmful roles. There are examples of microbial destruction in caves from rapid invasions and examples of adaptation strategies crucial to hierarchical biota sustainability (Boerner *et al.* 2006).

We were most interested to see if the datasets were demonstrating a microbial contribution of this latter kind. There is evidence in other cave environments to suggest that the biofilms of exposed surfaces can resist desiccation and suspend metabolism (Amann 2001). In response to stressors like extended drought, microbial biofilms can trigger various levels of dormancy with one study demonstrating successful reanimation after five decades of dormancy (Farnleitner *et al.* 2005). This project's results may be preliminary evidence to suggest that ORCA biofilms play a similarly beneficial role in sustaining the cave ecosystems through stressors and even retaining TOC as a food source for other cave biota, while simultaneously reducing their own consumptive needs.

Microbial influence or mitigation of pulses through a system needs to be better understood before it can be supported by resource managers. Also requiring further understanding is how disturbance events, drought, flood and fire might be beneficial to a cave or karst environment, even as it plays a detrimental role to a surrounding human environment.

Conclusion

We have learned that even in drought years, TOC can remain high; perhaps answering fears about certain short-term 'natural' impoverishment of the environment. And we have learned what may equate to a good survival probability for ORCA biota in specific regional contexts. If we understand better the internal mechanisms for resiliency in our cave system, we can make better decisions about how best to support their functions.

Toward that end, ORCA is initiating the following imperatives for improved cave and karst management:

1. Better hydrologic measurement techniques.
2. Measurement of inputs and outputs for the cave's hydrologic budget with appropriate error analysis.
3. Improved understanding of our fire-soil-water-vegetation-microbial-cave relations.
4. Find detailed long-term hydrologic and fuels reduction studies at other caves in Mediterranean settings.
5. Ongoing updates that will help build better models of regional climate.
6. Ongoing comparison of current to past hydrologic regimes and analysis of cave response to climate.

Minimally, our recommendations for climate change resiliency management include:

1. Monitoring for early warning/ projections
2. Risk /impact assessment
3. Mitigation/response

Future Recommendations

- Address dilution and elevation factors
- Conduct measurements of microbial and fungal biomasses pre-burns and post-burns
- Build worst-case scenario plans that include different levels of aggressive action alternatives. For example, reducing total surface vegetation in the immediate cave watershed by 20 percent
- Network with other cave and karst managers specifically on fuels, water, and microbial impacts for resiliency
- Continue to implement fuels reduction plots and monitoring as scheduled

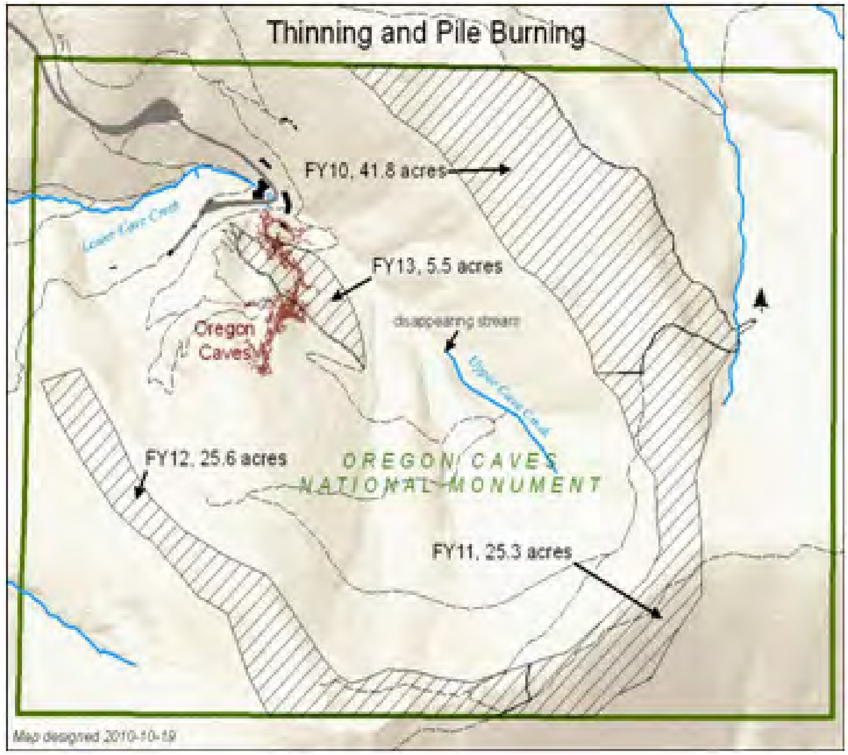

Figure 4. Future planned fuels reduction activity through fiscal year 2013 surrounding the cave Future planned fuels reduction activity through fiscal year 2013 surrounding the cave system.

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Lehman Cave Restoration Project

Ben Roberts
Chief of Natural Resource Management
Great Basin National Park
Baker, Nevada, USA 89311
775-234-7331 x 228
ben_roberts@nps.gov

Abstract

The Lehman Cave Restoration Project, funded through the Southern Nevada Public Lands Management Act, has restored 4,700 square feet of cave floor in Lehman Cave to a natural condition by removing over 800 feet of trails and 1,600 feet of electrical lines from the cave. These areas of the cave were closed to public use in 1981 following safety concerns in the Talus Room section. The project was carried out by park staff and volunteers from the Southern Nevada Grotto, a caving group of the National Speleological Society based in Las Vegas, as well as other cavers and grottos from Nevada and Utah. Volunteers removed trail, hauled buckets, and conducted an extensive before and after photo inventory. The concrete, asphalt, and sand making up the trail were removed one 5-gallon bucket at a time. Each bucket weighed over 55 pounds and staff and volunteers hauled over 2,232 buckets totaling over 61 tons of debris. While most of the work is out of sight of visitors, dramatic changes in the Sunken Gardens area, part of the 90-minute tour, are visible.

History and Need for Project

Since the discovery of Lehman Cave in the late 1800s, infrastructure developments have been installed to facilitate visitation but have adversely effected the natural cave environment. For the last 120 years, foreign materials consisting of wood, iron, steel, copper, tin, lead, asphalt and other materials have been continuously introduced. In the damp, biologically active, cave environment, all of these materials have deteriorated in varying degrees. Knowledge of human induced impacts to cave ecosystems has grown considerably in recent years. It is now recognized that the introduction of foreign materials has a profound and lasting negative impact on fragile cave ecosystems.

Trails have been constructed to form the tourist route and have been surfaced and resurfaced with numerous materials including asphalt, cement, and rubber mats. A portion of the cave trail system through the Talus Room and West Room were permanently closed in 1981 due to safety concerns. The first electric lights were installed in the cave in 1941 with additions in 1950. The electrical system was upgraded in 1970 and sections of the system were replaced again in 1977 and 1998. Although the lighting and electrical systems were upgraded, the old systems were left in place. Approximately 1600 ft of unused electrical conduit with associated wiring, switches, sockets, and transformers are along the abandoned section of cave trail.

The physical deterioration and chemical decomposition of foreign materials significantly threatened the cave by: disrupting natural cave processes; harming cave biota some of which are endemic to the cave; adversely impacting water quality; and creating a safety hazard to park visitors and staff.

This project proposed to remove all of the abandoned electrical system and trail, restore the areas, install photo points to document the before and after condition, and provide outreach to staff and visitors through a variety of media.

Project Implementation Methods

Disconnecting the abandoned electrical lines and installing new temporary power lines was the first step in the project. Staff discovered that the trunk transformer was still in good condition but the old junction box was completely rusted. Staff disconnected all old lines, installed a new connection to

Figure 1. Corroded light in Talus Room. NPS photo

Figure 2. Trail layers close-up showing rock, sand, dirt, asphalt, and concrete. NPS photo.

the transformer and then ran all power through a moveable junction box. This allowed the project to have power for lights, vacuums, and jackhammers. The old lines were traced out from the old junction box, cut into sections and rolled up for transport. At each light location, the light, fixtures, and concrete for a base or shielding was removed. All materials were loaded into 5-gallon buckets for removal.

When staff began the trail removal, they quickly discovered that the trail was made up of multiple layers. First, native rock and formations were used to construct the base of the trail. A layer of dirt and sand then followed. These layers were between 2 feet and 2 inches in depth, depending on the area. Above the dirt was a 1 to 2 inch thick layer of asphalt and above that was a 1 to 3 inch layer of concrete. To remove the trail, staff first used an electric jackhammer to break up the concrete and asphalt. Large pieces were loaded by hand into 5-gallon buckets and small pieces were scooped up with small trowels and brushes. Concrete and asphalt remaining on native rock and formations were removed with hammer and chisel, doing the least amount of damage possible to the cave. In some areas of delicate formations, it was determined that the removal of the concrete would cause unacceptable damage to the cave and so some small pieces were left. The area was then vacuumed to remove all sand, dirt, concrete, and asphalt. Native rock and formations were returned to the nearest approximate locations that they came from.

All materials were then hauled out of the cave in 5-gallon buckets. The first year staff utilized Radio Flyer wagons which were narrow enough to travel through most of the cave and able to carry three buckets at a time. Buckets weighed an average of 55 pounds apiece and so it took 2 people to maneuver the wagons through the cave. At stairs and 1 narrow section, the buckets would have to be removed, hand carried, the wagon hand carried, and finally reloaded at the bottom of stairs or on the other side of the constriction. The second year the park purchased narrow dollies that carried two buckets at a time, one stacked on the other. The dollies, coupled with the shorter haul distance as the project went on, enabled staff to haul material more quickly and safely. Over 61 tons of debris was removed from the cave in over 2,232 5-gallon buckets.

Project Implementation By Quarter

All locations can be followed on the accompanying map, Lehman_Cave_Map_With_Notes. Staff were not able to work full time on the project as they were in mandatory furlough status for multiple pay periods each year and were committed to tasks on other SNPLMA-funded projects at various times.

FY2008 3rd Quarter, April-June

Staff installed new temporary power and removed all the electrical wiring and lights in the Talus Room and North Talus Room. They began taking out the stairs and they removed the trail from the stairs to the northern most point, restoring all sections as they went.

FY2008 4th Quarter, July- September

Staff removed trail in the North Talus Room, restoring

Figure 3. Trail layers with buckets in background. NPS photo.

all sections as they went.
FY2009 1st Quarter, October-December

Staff removed trail in the North Talus Room, restoring all sections as they went.

FY2009 2nd Quarter, January-March

Staff removed trail in the Talus Room, restoring all sections as they went.

FY2009 3rd Quarter, April-June

Staff removed trail in the Talus Room, restoring all sections as they went.

FY2009 4th Quarter, July- September

Staff removed trail in the Talus Room, to the top of the stairs, restoring all sections as they went. In August staff moved all equipment to the Royal Gorge (between the Sunken Garden and North Talus Room) and began working towards the Sunken Gardens.

FY2010 1st Quarter, October-December

Staff removed lights and wiring and trail towards the Sunken Gardens.

FY2010 2nd Quarter, January-March

Staff spent considerable time removing debris that filled three large ponds between the Royal Gorge and Sunken Gardens. Asphalt, dirt and sand covered an area about 20 ft wide, 30 ft long and up to 2 ft thick.

FY2010 3rd Quarter April-June

Staff removed most of the trail in the in Sunken Gardens, including railing and railing anchors. Staff was unable to do the final restoration work due to high water levels. In June, staff moved all the equipment back to the top of the stairs in the Talus Room and began work there.

FY2010 4th Quarter July- September

Staff removed trail between Talus Room and West Room and all electrical wiring and lights in the West Room.

FY2011 1st Quarter, October-December

Staff remove trail through most of West Room.

FY2011 2nd Quarter, January-March

Staff complete trail removal in the West Room. Staff removed all old lighting and electrical lights in the Sunken Garden and install new lights. Staff began restoration of the pools in the Sunken Gardens.

FY2011 3rd Quarter, April

Staff completed restoration of the pools in the Sunken Gardens. Staff does final removal of all equipment from the cave, final cleaning of all equipment, and begin final report.

Interpretive Products

Project Manager and park interpretive staff developed several products over the course of the project to inform visitors.

Figure 4. Removing buckets from cave. NPS photo.

Interpretive staff was also trained each spring about the status of the project, how to deliver an effective tour that explained the project, and how to deal with potential disturbances as staff removed materials.

Inside Earth, Summer 2008 – Great Basin National Park, pg 10
Inside Earth, Summer 2009 – Great Basin National Park, pg 6
Inside Earth, Summer 2010 – Great Basin National Park, pg 3
Midden, Winter 2008–New Park Projects, pg 1
Midden, Summer 2008 – Cave Restoration in Talus Room, pg 2
Midden, Winter 2009 – 15 Tons of Debris Removed, pg 4
Midden, Summer 2010 – Lint and Restoration Camp, pg 3
Bristlecone, 2008-2009 – Talus Room Restoration, pg 15
Bristlecone, 2010-2011 – Lehman Cave Restoration Continues, pg 5
Bristlecone, 2011-2012 – Lehman Cave Restoration Completed, in press
Poster, 2009, The Talus Room Restoration Project
Site Bulletin, 2011, The Talus Room

Photo-Documentation

Park staff compiled hundreds of photos of their work in progress as the project went on. Additionally, the Southern Nevada Grotto, a group of cavers associated with the National Speleological Society and based in Las Vegas, took before and after photos of the entire trail area.

Figure 5. Sunken Gardens before. Photo by Rick Bowersox, Southern Nevada Grotto.

Figure 6. Sunken Gardens after. Photo by Rick Bowersox, Southern Nevada Grotto.

Current Cave Management Projects at Jewel Cave National Monument, South Dakota

Mike Wiles
Chief of Resource Management
Jewel Cave National Monument
11149 U.S. Highway 16 #B12
Custer, SD 57730
Mike_Wiles@nps.gov

Abstract

Jewel Cave National Monument conducts a variety of research, management, restoration, and monitoring projects to aid in the understanding and protection of Jewel Cave. Recent efforts include: 1) evaluating an "air curtain" to reduce the amount of lint introduced via the Scenic Tour route, 2) developing photomonitoring techniques that employ digital image arithmetic to evaluate slight changes over time, and 3) use of digital image sampling to streamline the monitoring of dust along establish travel corridors within the cave. This paper presents status of these proof-of-concept investigations, in order to encourage further research to develop and implement these new techniques.

Reconciling Speleothem Sampling for Paleoclimate Research with Cave Conservation

Sarah A. Truebe[1,2], Julia E. Cole[2], Michael Lee[3], Heidi Barnett[2,4]

[1] strube@arizona.edu
650-804-5413
[2] Department of Geosciences
Gould-Simpson Bldg #77, Rm. 208
1040 E. 4th St
University of Arizona
Tucson, Arizona 85721
[3] Artist/Exhibit craftsman
[4] Current affiliation: Ventana Medical Systems, Tucson, AZ

Abstract

In addition to being aesthetically appealing, cave stalagmites can provide high-resolution, absolutely-dated records of regional climatic change. However, sampling for climate records is inherently destructive; formations must be removed from caves, and material is consumed for geochemical analyses. Often, researchers remove multiple stalagmites from caves for analysis, without any thought to cave conservation. However, other groups have been much more conscientious in their attempts to develop new methods, and many paleoclimate scientists in the international community are starting to recognize the need to make speleothem paleoclimate research more sustainable. We propose that with a combination of careful site selection, sampling techniques, creative new methods for speleothem replacement, and archiving of materials, cave conservation and paleoclimate reconstruction can be reconciled. Here we use case studies from southern Arizona to demonstrate successful examples of site selection (including cave monitoring and modeling studies), sample selection (including observational data and preliminary sampling for identifying age-appropriate stalagmites), processing methods (including coring), and speleothem replacement strategies (including construction of "pseudo-mites"). We present these methods not necessarily as best practice, but rather to begin more serious discussions between cave managers, cavers, and paleoclimate researchers. As a community, we hope to develop best practice methods and employ them as soon as possible to avoid irrevocable damage to caves in the United States and worldwide.

Introduction

Speleothems, specifically stalagmites, can provide excellent records of past climate change because their growth and mineral, petrographic, and isotopic composition are sensitive to climate.[1,2] Because they grow relatively quickly in some environments, stalagmites may record climate changes at annual resolution or better.[3] In addition, some stalagmites can record climatic changes for very long time periods (100,000s of years), making them suitable to reconstruct past climate through multiple glacial-interglacial cycles.[4,5] Speleothem calcite incorporates small amounts of uranium, the decay of which can be used to date speleothem calcite with very high precision.[6,7] Finally, caves with speleothems are frequently found in areas (such as the Sonoran desert of North America) where there are few, if any, comparable records of past climatic changes.[8]

Speleothem sampling for climate reconstruction is inherently destructive, however, as analyses are conducted along the growth axis. Speleothems ought to be considered a non-renewable resource, and treated as such.[9] We believe there are ways to reconcile speleothem sampling for past climate (paleoclimate) reconstruction with cave conservation, and these (and other methods) should be implemented as soon as feasible. The remainder of this paper details a few case study approaches attempted by the University of Arizona Cave Research Lab and highlights a few larger community-scale efforts and requirements to reconcile these two seemingly conflicting resource management needs.

Case Studies

Our case studies and efforts to consider cave conservation while collecting material for paleoclimate reconstruction fall into three broad categories. The first includes screening sites for sensitivity to the climate variable of interest, such as precipitation amount, seasonal balance of precipitation, or temperature, similar to the approach described to identify cave sites sensitive to cyclone events in Frappier (2008).[10] Small-scale variability in cave sensitivity could arise due to heterogeneity in the epikarst, slope, aspect, topography, and so forth. Determining the sensitivity of a cave site can be done ether before or after a stalagmite is selected for paleoclimate analyses, but by selecting cave sites carefully from the outset, unnecessary sample removal is minimized. The second category is selecting specific stalagmites for sampling. Using a combination of methods, the ideal stalagmite samples for the ages and climate variables of interest can be selected, maximizing efficiency in sampling. There are a number of different approaches for sample selection, which are detailed below. The third and final category of cave conservation-friendly approaches to speleothem paleoclimate science is an effective processing and replacement strategy. Although the details of these strategies depend on the location and the scientists and cave managers involved, our current approaches are described below.

Site Selection

One way to minimize impact on the cave environment is to select a cave, and a site within a cave, that is responsive to the environmental variable of interest. We have achieved this via two methods. First, we have modeled cave dripwater chemistry at Cave of the Bells, AZ to show how responsive that cave is to monsoon rainfall.[11] Similarly, we have been monitoring a number of Southern Arizona caves (Figures 1 and 2) for isotopic variation in dripwaters and “farmed” calcite on frosted glass plates.[12] With monitoring, we have identified caves and sites within specific caves that are most responsive to monsoon rainfall. We have also identified that certain sites do not respond substantially to monsoon rainfall in the modern climate system, and as such, we are less interested to pursue past monsoon reconstruction at those locations. Even a seasonal, intermittent, or 1-year monitoring project may be enough for paleoclimate researchers to understand their cave system such that they can be more certain that they are reconstructing the variable they would like to understand.

Sample Selection

Once a responsive cave site has been identified, it is equally necessary to determine if the stalagmites in the cave cover the range of ages that are desirable for climate reconstruction. Some parts of a cave may precipitate calcite for thousands of years and then abruptly stop for thousands of years,[8] perhaps due to variation in cave ventilation, precipitation of calcite in the epikarst, or even climatic changes at the surface. By monitoring which stalagmites are actively growing, either with frosted glass plates as in our work, or even with monthly or seasonal photomonitoring, scientists are more likely to determine which stalagmites are actively growing and thus might be suitable for more recent climate reconstruction.

We have also screened stalagmite ages by taking small (< 1 cubic centimeter) samples and using uranium series decay dating to determine their ages.[6,7] If U-Th dating is prohibitively expensive, radiocarbon dating may be a viable alternative for “ballpark” ages on stalagmites. This method assures that researchers will be using only those stalagmites that span the age range of interest.

Finally, by working with cave managers and show cave developers, it is possible to use already broken material

Figure 1. Monitoring setup in Kartchner Caverns State Park. Project design incorporates a glass plate to “farm” calcite, a funnel, a water bottle for water collection, and a tripod to avoid impact on the cave surface below. Laminated identification card was zip-tied to tripod on a later trip. Photo: Sarah Truebe.

for paleoclimate reconstruction. Although some information is lost not knowing under what type of formation broken stalagmites grew, broken pieces still hold useful climate information.

Figure 2. Monitoring of environmental variables such as temperature and humidity in a S. Arizona cave using HOBO loggers. Photo: Jansen Cardy.

Stalagmite Processing and Replacement Strategies

How and if the speleothem will be replaced in the cave must be considered immediately, even before sampling has begun. In the past, our lab has collaborated with others to core stalagmites then epoxy them back into place in the cave with a calcite cap per our agreement with the U.S. Forest Service (Figure 3). For an actively growing formation, the aesthetic damage is temporary. This arrangement is not ideal for climate researchers, as being able to see the entirety of the stalagmite, not just a core, is very helpful for optimal sampling and interpretation. Some remineralization changes throughout the formation's history may not be entirely visible in the external morphology or in a core of the stalagmite, which can make paleoclimate reconstruction difficult if not impossible. A full slab of a formation may be helpful to determine where there are changes in speleothem growth patterns that could affect interpretation. In very sensitive areas, however, coring in-cave remains a reasonable option to minimize long-term damage to the cave.

Another option may be to take a thin slab from the center of a stalagmite, trim the edges, and rebuild the stalagmite. This allows paleoclimate researchers to have a full cross-section of the stalagmite, but also leaves the stalagmite in the cave long-term. Restoration/replacement might be the best option if cave restoration techniques and methods training are available for paleoclimate scientists and stalagmites are actively growing.

A completely different option would be to remove the speleothem entirely and replace it with a scale replica. We worked with a local artist to develop finely-detailed casts of a stalagmite (methods available on request). One such cast was cleaned and placed in Kartchner Caverns, a show cave in southeast Arizona, in July 2011, to see if it will grow fungus or bacteria (Figure 4). As of November 2011, the stalagmite exhibits no biological growth of any kind. There are a number of pros and cons to this "pseudomite" replacement approach (see Table 1). This may be a viable option where the cave aesthetics are critical, as even a restored formation after it has been cored or slabbed may exhibit some lingering visual effects.

Figure 3. A cored speleothem after replacement in the cave. Photo: Toby Ault.

Discussion

The cases discussed above are only a few options to begin to reconcile cave conservation and paleoclimate research. Although each approach is progressing towards a more cave conservation-friendly sampling method, there are issues with each. For instance, monitoring a cave site to determine its responsiveness to environmental variables takes time, effort, and funding which may not be available to paleoclimate scientists. Similarly, pre-sampling stalagmites via monitoring or dating is costly in terms of analyses, time, and potential harm to the cave environment from many trips into the cave and small samples taken from many stalagmites. Furthermore, in some areas, uranium concentrations may be prohibitively low to screen for samples of the appropriate ages before sampling. Finally, stalagmite sampling and replacement may not be effective for paleoclimatologists who have no training in cave restoration techniques. Low-impact sampling strategies require extra effort that many paleoclimate scientists are not willing to pursue without a deeper understanding of cave ethics. Not all strategies may work in all settings, and conversations between cave managers and paleoclimate scientists will be necessary to establish effective and conservation-friendly protocols.

On the community scale, there are attempts to reconcile paleoclimate sampling and cave conservation, though those efforts are in their infancy. Fairchild and Baker (in press) suggest that speleothems ought to be treated as "archaeological" material, with a sense of non-renewability and respect.[9] They also recommend that speleothem material be archived and cataloged digitally such that future researchers can access samples and data without re-sampling caves. However, paleoclimate researchers have neither the time nor the funding to construct a large database of geochemical data and stalagmite samples. Support from national and international groups, perhaps including regulation of speleothem samples similar to that of archaeological material, may be necessary for climate scientists to begin sampling and archiving speleothem material more responsibly. It may also be necessary for paleoclimate scientists to interact with cavers and cave managers such that as a community, paleoclimatologists begin to appreciate cave speleothems as finite resources. There are many individual labs already taking these important steps, but much more can be done at the community level.

Fundamentally, removing material from the cave – be it a core, a slab, or a whole stalagmite – compromises the existence value of caves. Caves are complex natural resources with a wide variety of benefits to humans, cave biota, groundwater

Figure 4. A "pseudo-mite" made of cement and marble sand sitting in Kartchner Caverns to determine if the material will grow bacteria or fungus. Photo: Ginger Nolan.

systems, and so forth. Many people receive a benefit knowing that caves and speleothems exist undamaged, even if they do not visit them, similar to how knowing the Amazon rainforest or the Grand Canyon exists may give certain people a positive benefit (that is, a "sentimental value").[13] All these methods to reconcile cave conservation compromise the existence value of cave resources. Even if it were possible to balance a negative effect on the cave – speleothem sampling – with a positive effect, such as funding or time volunteered for cave restoration, trail maintenance, public education, and so forth, the existence value of stalagmites remains compromised. This will likely lead to difficult but necessary conversations between scientists and cave managers as we continue to value and need past climate information from caves.

Conclusions

Reconciling speleothem sampling with cave conservation is critically important and eminently achievable. A combination of methods, discussed at length between cave managers and paleoclimate scientists at specific locations could be used to select the best possible sample(s) for paleoclimatology in the least damaging way. On a small scale, teaching paleoclimate scientists good caving ethics and restoration techniques may begin to have an effect on the community overall. On a larger scale, more organized efforts of archiving and making samples available to future researchers will be necessary to prevent further impact on our finite natural cave resources.

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Table 1. "Pseudomite" replacement strategy

Pros	Cons
• No long-term aesthetic impact on the cave • Made of pure calcium carbonate cement and a fine marble sand; precise color matching possible • Stalagmites can be "replaced" immediately • Archived stalagmite remains available to future researchers, preventing further cave damage.	• Existence value remains compromised (see discussion) • Potential microbial impact on cave? Uncertain long-term (10-100yr) impact on cave • In-cave molding could be very expensive

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Volunteers: What Can We Do for Them?

Bonny Armstrong
110 Timber Lakes Estates
Heber City, Utah 84032
480-861-1807
bonnyarmstrong@gmail.com

James Goodbar
620 E. Greene St.
Carlsbad, New Mexico 88220
575-234-5929
james_goodbar@blm.gov

Abstract

The importance of volunteer service to cave resource management programs has long been recognized and written about. Cavers donate vast amounts of man-hours worth hundreds of thousands of dollars in monetary value each year. Their volunteer service is highly specialized with specific types of work that would be considered as "scarce skills" in the government. This includes cave surveying and cartographic map production, resource inventories, specific scientific research such as microbial, mineralogical, and hydrological studies, and assistance with writing cave-specific search and rescue, and management plans. These tasks are operations that many cave resource managers could not afford to hire for but are essential for the effective and responsible management of cave and karst systems. What has been given only minimal attention is what agencies can do to give recognition and rewards back to volunteers who donate so much time, talent, and energy. This paper will discuss not only how volunteers can be rewarded but more importantly how to ensure volunteers are pleased with their working environment and motivated by their assigned tasks so that they will want to continue their volunteer service.

Based on research provided by national volunteer organizations (such as the Peace Corps, the Corporation for National and Community Service, Volunteer Match) and personal experience, the authors have identified four key topics to consider when managing volunteers. These topics include: giving volunteers enjoyable and meaningful work, offering training and orientation, providing supervisory attention and feedback, and recognizing and rewarding volunteers for a job well done.

Give Volunteers Enjoyable and Meaningful Work

Understanding why cavers volunteer is necessary to help them get the most out of the experience and taking the time to ask will benefit them as well as managers. Cavers volunteer for a variety of reasons but here we consider four primary reasons.

The first can be lumped into a term called *skill set*. Some cavers wish to bring specialized skills to a project. This may include cave surveying, cartography, cave photography, or GIS skills. Find out what their specialties are and utilize them. Don't pigeon-hole them, though. Allow for task diversity to avoid burnout and encourage them to try something new. Others may be looking to learn new skills for personal or career reasons. Provide mentoring to help them learn these skills to reach their desired goals.

Many people, including cavers, see volunteerism as a means of *personal growth*. Working on a volunteer project may help them in education or career choices, fulfill a sense of responsibility or civic pride, or cultivate a new interest.

Contact with others is a great motivation for signing up for a volunteer project. Cave projects introduce cavers to others with similar interests on a social and professional level.

Volunteer cavers are somewhat unique in their passionate desire to be involved with *resource protection*. It is something they often spend large amounts of personal time on already, so organized projects such as cave locating, surveying, and inventory can receive a big turnout of volunteers. This is especially true when the project involves "high-profile" caves or areas with restrictive access such as Lechuguilla Cave.

Offer Orientation and Training

Research has shown that a lack of orientation and training is often a volunteer's biggest frustration. While we may think our agency's mission is obvious to everyone, it is not, and volunteers are often surprised that federal agencies can have different goals and missions. Taking the time to introduce your volunteers with a short program or slide show will help them better understand their role.

Volunteers should be introduced to the entire staff and made to feel like part of the larger team. At anytime during their service, they should be able to answer these three questions: 1. Who do I work for? 2. What is my job? and 3. Where do I get the tools that I need?

Even the most experienced cavers should receive some training in cave conservation and safety before the start of any project. Eastern cavers coming to the west may need to be reminded to bring pee bottles into a cave. Western cavers volunteering in the east should be introduced to poison ivy, etc. All projects should begin only after a safety session discussing all possible hazards. Most agencies now make use of Job Hazard Analyses (JHAs), also known as Job Risk Analyses, which both staff and volunteers read and sign before beginning an activity. Any appropriate agency-required training for staff should also be made available for volunteers.

Another type of training that can be considered as an award is to send a volunteer to the National Speleological Society (NSS) annual convention or other national or international caving conference, symposium, workshop, or convention. In this way, the volunteer is representing the agency and can be reimbursed for their expenses and have their registration paid for by the agency. This gives the volunteer an opportunity to interact with the caving community in an official capacity and gain experience and knowledge in the field of speleology in an all-expenses paid setting.

Provide Supervisory Attention and Feedback

Building interpersonal relationships among volunteers, staff, and management makes for a better team environment and more enjoyable work atmosphere. These relationships are enhanced when volunteers are included in staff meetings and communications, making them feel like part of the larger team. Volunteers will also appreciate supervisory attention which can be as simple as asking them, "How are you doing?", "Are you comfortable with your team and task?", or "Do you need anything?" Remember, communication is a two-way street so listen to and address any concerns they may have.

Depending on a volunteer's reason for service, they may ask for a formal evaluation, especially if they are seeking employment in a related field. Provide an honest and constructive evaluation, as it will surely enhance their performance. Otherwise, feedback for volunteers is best done in an informal setting. Gathered in a group, you can thank and praise everyone as a team. You can also use this time to address issues without singling out any one person. For example, before heading into the cave you might conduct a short session where you could say, "Thanks, everyone, for all of your hard work yesterday. We made a lot of progress. Today, let's try to not muddy the tourist trail handrails with our gloves."

Recognize and Reward Volunteers for a Job Well Done

In the true spirit of volunteerism, most cavers do not expect anything tangible for their efforts. Volunteers, however, are vital to responsible cave management programs and managers should not hesitate to show their appreciation through various types of recognitions and awards.

Special recognition for volunteers, individually or as a group, can be done within an organization or in the larger community. Ideas for recognition within an organization can include certificates of appreciation, volunteer of the month or year programs, pictures in newsletters, staff-hosted potlucks, and agency-sponsored volunteer banquets. "Promotions" to more responsibility also show a volunteer that you think they are doing a great job. Volunteers appreciate being recognized within the larger community, such as through media coverage. This can be through the local newspaper, community radio spots, in the NSS News or regional caving publication, or other media. Cavers can also be recognized and presented awards during local grotto meetings or at the NSS annual convention. Visit www.caves.org/committee/award/ for information on how to submit names for the many awards.

Federal agencies offer special awards for volunteers. The U.S. Forest Service has awards specifically tailored for their volunteers including Dedication to Service, Special Skills, A Job Well Done, and Outstanding Performance awards. Volunteer cavers for the BLM have twice received the BLM National Making a Difference Award which includes an all-expenses-paid trip to Washington D.C. to receive the award from the BLM Director. This award went to a group of cavers in 2002 and an individual caver in 2008. The BLM has also nominated cavers for the NSS's Victor A. Schmidt Conservation Award, which they received during the national convention.

Beginning January 1, 2007, volunteers who contribute 500 hours or more to a federal agency qualify for an America the Beautiful National Parks and Federal Recreational Lands Pass. This pass provides one year's access to all national parks and federal lands that charge an entrance or standard amenity fee.

Depending on your agency's guidelines, special items may be purchased for volunteers. Items with the agency's logo, such as coffee mugs or hats are a nice gift that won't break the budget. An online site called The Arrowhead Store offers a large assortment of items with the NPS logo that can be purchased for park service volunteers. T-shirts commemorating a project are always a hit with volunteers and shirts designed for the Jewel and Wind Cave Lint Camps by caver/artist Bonnie Curnock have become collector's items over the years.

Another special way to reward caving volunteers is with items such as helmets, cave packs, carabiners, caving lights, or gift cards to cave vendors.

Hard working and caring volunteers make a difference in responsible cave management and many programs depend on them. It is the responsibility of cave managers to nurture these volunteers, to show them appreciation, to enhance their volunteer experience and, above all, to say "thank you."

Building a Successful Trip Leader Program

Andy Armstrong
Division of Science and Resource Management
Timpanogos Cave National Monument
RR3 Box200
American Fork, Utah 84032
andy_armstrong@nps.gov
801-492-3647 ext. 502

Abstract

Proper management of public caves requires partnership with cavers. How can managers give cavers an active role in cave management while ensuring that agency goals and requirements are being met? One of the most effective ways of doing this is to build a trip leader program. This allows managers to manage a smaller amount of trip leaders, with them in turn managing other volunteer cavers. Trip leader programs provide a sense of ownership for volunteer cavers. When the system is built on mutual trust and respect, and volunteers are treated as extended staff, many mutual goals can be accomplished. Focusing on the trip leader training program enacted at Jewel Cave National Monument in 2006, the essential components of a successful trip leader program will be discussed and evaluated.

In 2007, Jewel Cave National Monument developed and implemented a new trip leader program (TLP). The program was created by Rene Ohms and Andy Armstrong, Physical Science Technicians in the Division of Resource Management at Jewel Cave (JECA). A TLP can be a helpful tool in managing public cave resources. This paper will discuss the necessary components of a successful TLP, using the JECA program as an example.

Volunteer trip leaders can provide great support to cave resource management. Managers are not always able to accompany every cave trip underground. However, access must be provided for in some way. A viable TLP offers a manageable span of control, allows for implementation of agency policy underground, and provides for accountability between cavers and managers. Most of all, volunteer trip leaders become "extended staff," allowing managers to do more than ever before.

Most caving parks deal with many individual cavers. At JECA, over 50 different people contribute to exploration and survey in a calendar year. It is often exhausting of time, energy, and resources to have to deal individually with each caver. Having trip leaders allows for a chain of command, where the park communicates with the trip leaders, and the trip leaders communicate with the participants on their trips.

Caves in national parks and on other public lands must be managed by a cave management plan (CMP). A CMP defines limits of acceptable change, roles and responsibilities, and allowed behaviors. Having trip leaders on each trip that have been trained on the intent of the plan is one of the best ways to ensure that policies are being adhered to underground.

A TLP sets up a system of accountability. In exchange for permission to visit the cave, the trip leader is responsible for reporting back to the park and submitting survey data, inventory data, and a written trip report. This way, managers can have a clear view of what is happening on cave trips. The program also provides accountability to trip leaders, giving them a clear expectation of what the park's responsibilities to them are.

TLPs are the right management strategy for certain caves. They are not necessary for every cave. Within a CMP, caves are often arranged in a hierarchy based on how sensitive their resources are to impact. In the most basic possible version of this, the least sensitive caves are open, while the most sensitive caves are closed. Open caves may or may not require a permit, but permits are generally given out freely for caves in this category. On the other end of the spectrum, some caves have such sensitive resources that they have been closed to access. There are some caves that lie somewhere in between these two extremes. These are the caves that can benefit most from a TLP. In the in-between caves, there are legitimate needs for access but also many sensitive resources that must be protected. A TLP can help to bridge this gap by providing trained, competent cavers who are available to take others in.

TLPs can help to bridge another gap as well, the gap between cavers and managers. Managers are often unfamiliar with caves and caving, or are too busy with other tasks to accompany every trip. Most of all, managers must comply with law, regulations, and the agency mission. They have a need to learn about the cave resources that they manage. Managers also often need volunteer help in order to implement policy and complete projects.

Cavers want to go caving. This is usually their overriding concern. Cavers will generally even follow agency policies that they do not agree with in order to get the privilege of access to premier caves. Cavers may not understand agency rules and missions if they have not been communicated clearly. The overwhelming majority of cavers sincerely want to protect the resource. It is also important to remember that cavers have a legitimate right to access public caves.

Unfortunately, sometimes the interests of cavers and managers are seen as a conflict. When the two sides do not understand one another's responsibilities, rights, and desires, it is easy to slip into an Us vs. Them type of attitude. Fortunately, at least in the world of cave management, we have a cure for the Us vs. Them mentality. It is a program that creates trip leaders. What a TLP does is to bring unity by making the "them" a part of "us." When everyone is on the same team, mutual goals are more easily accomplished.

The vast majority of Jewel Cave has been discovered since 1959. Before that time, less than two miles of cave were known. The explorations of Herb and Jan Conn revealed about 64 miles of cave over the next 20 years. They had a special use permit from NPS and basically all exploration trips were led by them. When they retired from caving in the 1980's, they handed exploration over to Mike Wiles, their apprentice. Mike and his teams explored another 71 miles of cave, bringing the total to 135 miles by 2006. As with the Conns, virtually all trips were led by Mike. Whether or not this access policy was fair, it did foster cohesiveness and the passing down of Jewel Cave-specific techniques and ethics.

When JECA cave managers developed their trip leader training program in 2007, they had several goals in mind. A primary aim was to avoid a list of rules as much as possible. Instead, the goal was to build a system of mutual trust, respect, and shared responsibility. Also, JECA was looking to provide more open access, while maintaining continuity with current practices and tradition. The challenge was to open exploration to more people, while maintaining the cave ethics and traditions that had been passed down under the previous system.

A basic TLP consists of three main components: prerequisites, a training program, and a system for maintaining and losing trip leader status. This allows prospective trip leaders to work up to eligibility, be trained on policy, and then work to keep their status.

Prerequisites usually take the form of time spent in the cave. This can be measured in hours or number of trips. Depending on the complexity and sensitivity of the cave resources, the prerequisites can be easy or more challenging to reach. For example, Lincoln National Forest traditionally required three work trips in a cave before achieving status in that particular cave. Wind Cave National Park requires ten trips in the cave to be eligible for the trip leader class. At Jewel Cave, where cavers' hours are recorded in a database, 100 hours was eventually settled on as the prerequisite. Resource managers originally argued for 250 hours, but this was reduced after public comment felt this to be too high. Because of the reduction in the prerequisite, additional information was added to the training program in order to make up the experience gap.

An alternate idea for a prerequisite would be to base participation in trip leader training on a skills requirement such as physical fitness or a single rope technique (SRT) test. The National Cave Rescue Commission has a set of entrance skills that students must demonstrate before taking one of their rescue classes. These could be easily adapted for trip leader prerequisites and can be found at www.ncrc.info.

The second component in a TLP is the trip leader training. This training can be a class, a PowerPoint that is sent to prospective trip leaders, or an in-cave training trip. The nature and complexity of the training should reflect the nature and complexity of the cave resource. For Jewel Cave, it was necessary to construct an eight-hour training course. Some of the topics covered include: rules and policies, Jewel Cave special issues, emergencies and SAR, survey, and inventory procedures. For other caves, the training may be as simple as a 20 minute PowerPoint that leaders are required to watch. Whatever version of training is enacted, it is important to offer it on a fair, regular basis. For example: if budget, time, or logistics limit the training to once per year, then every effort should be made to schedule it at a convenient time for participants and to announce it well in advance.

The final component of the program is a system for maintaining and/or losing trip leader status. This is usually a requirement to participate in a cave trip during an established interval of time. For example: at Jewel Cave, trip leaders must participate in two day-trips per year or one camp-trip per year in order to maintain status. If trip leaders are absent for one year, they must go on a trip as a participant and meet with cave managers to discuss any policy changes in order to re-obtain status. The idea behind this is that trip leaders stay up to date with policy as procedures change throughout the years.

TLPs can be a very effective way to encourage teamwork between cavers and managers and to ensure that agency goals are being met. At JECA, 35 trip leaders are now approved to lead trips in the cave. About 20 miles of cave have been discovered and surveyed since 2007.

Cave Rescue Pre-Planning at Wind and Jewel Caves, South Dakota

Rene Ohms
Jewel Cave National Monument
11149 U.S. Highway 16 #B12
Custer, SD 57730
rene_ohms@nps.gov

Anmar Mirza
3430 Huron-Williams Road
Williams, IN 47470
anmar.mirza@gmail.com

Marc Ohms
Wind Cave National Park
26611 U.S. Highway 385
Hot Springs, SD 57747
marc_ohms@nps.gov

John Punches
633 W. Hazel Street
Roseburg OR 97471
johnpuncheslIc@riousa.com

Abstract

Wind Cave National Park and Jewel Cave National Monument have completed the first phase of a cave rescue pre-plan. The pre-plan concept is based on previous work at Lechuguilla Cave, New Mexico, and involves evaluation of obstacles along main travel routes in the caves to prepare for a rescue. Specific anchors, gear needs, extrication techniques, and any modification requirements are noted for each obstacle, and are documented with photographs and diagrams. Such pre-planning can save valuable time and resources during a rescue. The plans emphasize small party and minimal gear techniques, which are necessities in remote areas of Jewel and Wind Caves.

Introduction

Wind Cave (>137 miles) and Jewel Cave (>155 miles) are two of the longest cave systems in the world. Both caves are managed by the National Park Service (NPS), and have active caving programs that provide access to cavers and the general public for recreation, research, and survey. The caves are just 35 miles apart, which provides great opportunities for collaboration on a variety of projects. The parks have nearly identical cave search and rescue plans and shared rescue callout lists, and have worked together to host joint rescue trainings for staff and local cavers.

Jewel and Wind present similar challenges for cave rescue. Both are well known for tight crawlways, mazy complexity, long underground travel times and distances, and delicate passages. It takes a group of fast cavers more than 6 hours one-way to reach the currently-known end of Wind Cave, and more than 10 hours to reach the end of Jewel. The caves are also located in a low-population state, where there are only a handful of active cavers. Cavers from other states often travel great distances, driving 6 hours or more, to participate in trips. The limited rescuer resources available, combined with high levels of use at each cave and the difficulty and remoteness of many of the trips, make it essential for the parks to be well-prepared for rescue and to ensure that it is as efficient as possible.

The Pre-Plan Concept

The current cave search and rescue plans at Wind Cave National Park and Jewel Cave National Monument guide the general rescue philosophy for each park. These planning documents are intended for use by management and cover the first steps to be taken in an incident, callout procedures, and broad options for team structure, communications, and litter extrication.

A cave rescue "pre-plan" is designed to be far more detailed and provide information on how to move a patient past specific obstacles underground. The concept was first developed by Mirza and Punches at Lechuguilla Cave, New Mexico in 2004 (Punches et al, 2005), where such advanced planning has proved to be a useful tool for increasing the overall efficiency and speed of rescue operations and reducing impact to cave resources.

During the pre-planning process, rescue obstacles such as tight constrictions, vertical drops, or delicate areas are identified, and the gear, anchors, techniques, and time required to move a patient through the obstacle are determined. Photos or drawings of each obstacle are annotated with instructions for anchoring, rigging, litter-handling, and/or passage modification, and any special techniques, patient packaging considerations, and recommendations for avoiding delicate cave features are noted.

In order to save valuable time and resources during a rescue, the pre-plan focuses on small party and minimal gear techniques. Given the considerable challenge in accessing the remote parts of Wind and Jewel Caves, it is critical that teams carry no more than they need to complete the task. The systems also need to be simple to operate, using as few rescuers as possible.

The final pre-plan document for each route includes a short overview of the obstacles between the farthest point and the entrance, in that order. The overview can be used by the incident command team to see, at a glance, how many teams they will need to send into the cave for different purposes. Detailed rigging, operation, and/or modification instructions for each obstacle follow and are designed to fit onto one or two pages that can be brought into the cave (Figure 1). These sheets also include a gear list and estimated times for completion of the task and system operation.

Wind / Jewel Pre-Plan Project

In 2010, Wind Cave National Park and Jewel Cave National Monument entered into a contract with Anmar Mirza and John Punches to complete rescue pre-planning work for several main routes through each cave. The contract also included a training component, whereby Mirza and Punches would train park staff on pre-planning concepts. This was done to ensure that the work could be continued for other routes in the caves after the completion of the contract.

Mirza and Punches traveled to the Black Hills three times to complete the contract work, in 2010 and 2011, and were able to develop pre-plans for more than three miles of cave passages (Table 1).

In March 2011, the parks invited local cavers to help test out elements of the pre-plans. This was combined with Mirza and Punches' final contract visit, and provided an opportunity to expand on the training element by offering training to 13 additional cavers.

Cavers from South Dakota and Colorado spent a day at each cave and tested the pre-plan at the Cloudy Sky Room and Diving Board in Jewel Cave, and at the Rescue Pit in Wind

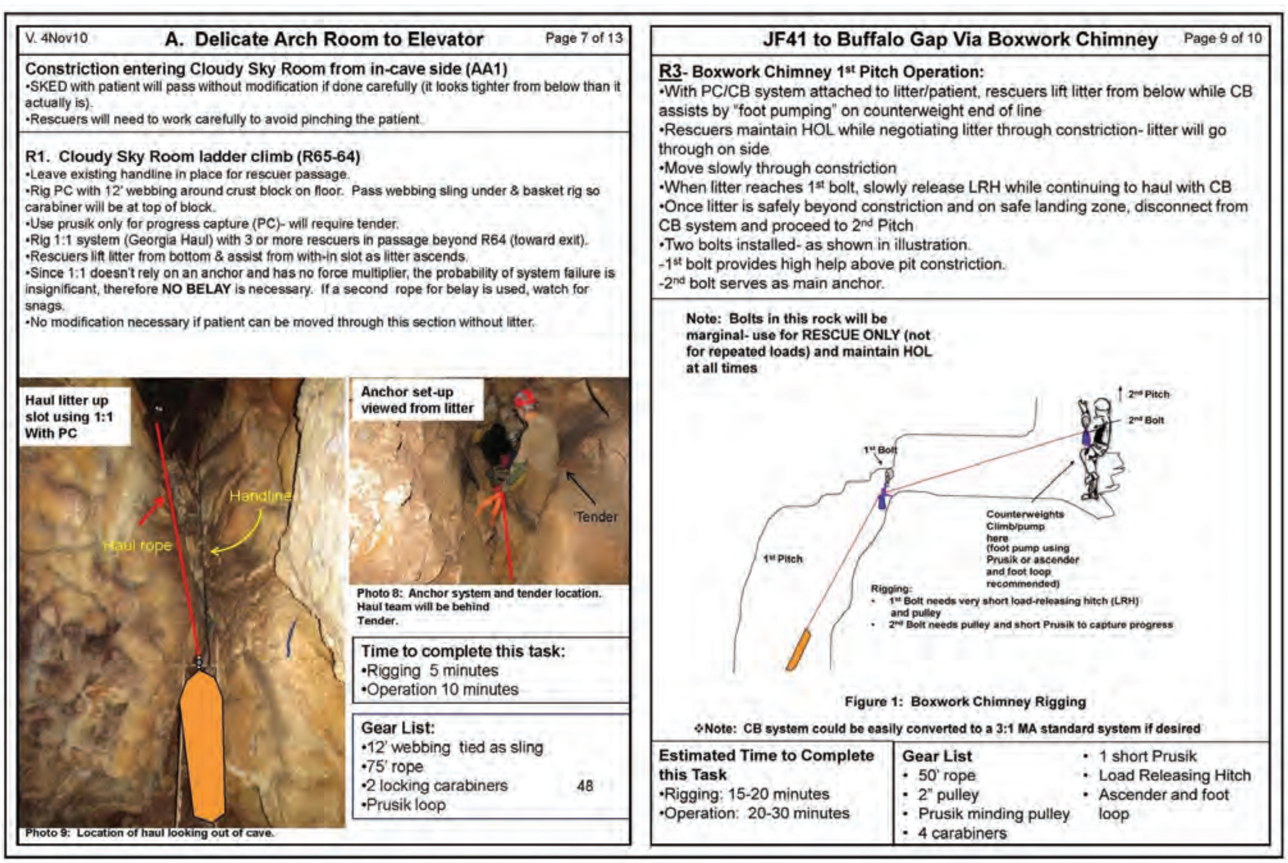

Figure 1. Pre-plan Examples from Jewel Cave (left) and Wind Cave (right)

Jewel Cave	Wind Cave
Black / Blue Tapes: Miseries to end of Mind Blower	Red / White Tapes to Half Mile Hall
Wild Caving Tour	Wild Caving Tour
Hub Loop	Bishop Fowler's Loop
	Yellow Tapes to Archimedes Pool
	Blue Tapes to Lakes

Table 1. Rescue Pre-Plan Routes Completed

Cave (Photo 1). Many of these cavers had minimal prior rescue training but were able to build and operate the systems using the pre-plan documents.

In September 2011, Jewel Cave National Monument and Wind Cave National Park hosted a National Cave Rescue Commission (NCRC) Regional Seminar, offering free training to 25 local and regional cavers and park staff who could assist in the event of a rescue at either cave. The mock rescue was held on Jewel Cave's Hub Loop and was another opportunity to test the pre-plan (Photo 2). All technical rigging for the mock was accomplished using only two short ropes, three carabiners, and two pieces of webbing, including a belay prudent for training activities. This is a great testament to the pre-plan's ability to encourage rescuers to utilize simple, yet safe and highly effective approaches to the cave's obstacles.

Next Steps

Wind Cave recently completed pre-planning for the pink-and-black taped trail to Mammoth Canyon and began work on the pink taped trail to the Chimera Room. Jewel Cave will continue the black-and-blue taped trail in the winter of 2011. Both caves anticipate completion of pre-planning for all of the most frequently used caving routes by 2014.

Since 2008, the number of individuals in South Dakota with any level of cave rescue training has increased exponentially as a result of the opportunities offered by the two parks. Each park also now has a qualified NCRC instructor on its staff and intends to host additional trainings whenever feasible to help build a local cadre of rescuers.

Jewel Cave National Monument and Wind Cave National Park have taken many steps to prepare for cave rescue and the recent pre-planning effort represents a significant advancement. This project positions the parks to be much more efficient and effective should a rescue occur, and the training offered by Mirza and Punches to staff will allow the planning efforts to keep pace as exploration continues.

Training trip leaders and other cavers on the techniques found in the pre-plan can prevent larger rescues by allowing more self rescues to occur. Pre-planning, combined with an ongoing commitment to train area cavers in rescue techniques, has allowed Jewel and Wind Caves to be significantly better prepared for cave rescue incidents.

Photo 1. Climbing Counterbalance at Wind Cave's Rescue Pit. Anmar Mirza Photo.

Photo 2. Lowering the Mock Patient on the Hub Loop at Jewel Cave. Anmar Mirza Photo.

Acknowledgements

Thanks to Kelly Mathis for his work on the pre-plan documents, and to the park superintendents, Larry Johnson (Jewel Cave) and Vidal Davila (Wind Cave), for their support of this project.

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Caves and Karst of the Providence Mountains Study Area, Mojave National Preserve: Building Upon Decades of Volunteer Contributions

Bernard W. Szukalski
Esri
380 New York Street, Redlands, CA 92373 USA
bszkalski@esri.com

Tom Gilleland
MineGates, Inc.
4980 N. Campbell Avenue, Tucson, AZ 85718 USA
tom@minegates.com

Ted Weasma
Mojave National Preserve
2701 Barstow Road, Barstow, California 92311 USA
ted_weasma@nps.gov

Abstract

The Providence Mountains are located in the eastern Mojave Desert in San Bernardino County, California, and are one of the major carbonate ranges now located within the Mojave National Preserve a 1.6-million-acre unit established in 1994 by the California Desert Protection Act.

In 2010, a study area in the Providence Mountains was designated by the Mojave National Preserve (MOJA), in the award of a contract to locate and inventory caves and rock shelters and update information on all existing National Park Service (NPS) caves within its limits. The study area encompasses a roughly16-square-mile area in the heart of Bonanza King Canyon – one of several major limestone canyons on the east side of the range, and an area with a rich speleological history that has received the attention of cavers since the 1960s.

The foundation of the MOJA cave database was established using early published reports, anecdotal information, and subsequent contributions from National Speleological Society (NSS) cavers, the Cave Research Foundation (CRF), and park staff. This latest project brought together park personnel, contractors, and volunteers in a successful relationship that met project goals as well as preserved the history of earlier work.

The database was used to derive GIS maps and other digital mapping products to facilitate exploration, identification, and understanding of caves in the area. The final report includes the updated database with 133 caves and other features, new and updated maps, a biological inventory, a discussion of geology, and GIS maps and data products.

Setting and Background

The Mojave Desert and Mojave Desert Ecosystem encompass more than 80,000 square miles and include portions of California, Nevada, Arizona and Utah. The area represents an extremely diverse environment encompassing the lowest and highest points in the United States (Mojave Desert Ecosystem Project, http://www.mojavedata.gov). The greater Mojave Desert also includes many national parks, monuments and scenic areas, as well as state parks and preserves.

Near the center of the Mojave Desert lies the Mojave National Preserve. The preserve was established by the California Desert Protection Act of 1994 and includes roughly 2,500 square miles, or roughly 1.6 million acres, of which nearly 700,000 acres are designated wilderness. The Mojave National Preserve ranges in elevation from a low of 880 feet near Baker, California, to high of 7,929 feet at the summit of Clark Mountain, located in the northern limits of the Preserve (Mojave National Preserve, http://www.nps.gov/moja). The Mojave National Preserve is the third largest NPS unit in the continental United States, behind Death Valley National Park and Yellowstone National Park (National Park Service, http://www.nps.gov).

Nearby Cave Resources

Near the Mojave National Preserve are areas with significant cave resources. Three areas of note include Mitchell Caverns, the Kokoweef Peak area, and the Pisgah lava flow.

Mitchell Caverns is part of the California state park system and Providence Mountains State State Recreation Area. It is located in the southern Providence Mountains, surrounded by the Mojave National Preserve. The caverns are seasonally operated for public tours (California State Parks, http://www.parks.ca.gov/default.asp?page_id=615). Mitchell Caverns (currently closed due to State budget issues) consists of two caves, El Pakiva and Tecopa Caverns, connected via a man-made tunnel. The total length of the cave (including the connection tunnel) is 1,476 feet with a depth of 84 feet.

Also within the State Recreation Area is Cave of the Winding Stair, an unimproved cave first made famous by William R. Halliday in his book Adventure is Underground (1959). The cave was surveyed to a length of 1,954 feet and depth of 311 feet in 1971 by members of the Southern California Grotto, NSS (Arnold, 1971). Other smaller caves have been recorded in the state lands. The Pisgah area is a basaltic cinder cone and lava flow located to the southwest of the Preserve boundary and located primarily on Bureau of Land Management (BLM) land. Hundreds of caves are known in the area and while most are small, several are of considerable size and dimension. The longest is over 1,000 feet long (Harter, 1992).

The Kokoweef area was also highlighted by Halliday (1959) in his book Adventure is Underground. In 1972 members of the Southern California Grotto visited the area and mapped several caves, including Crystal Cave which was surveyed to a length of 367 feet (McIntosh, 1972). The area is most known for a fabled and mysterious lost cave – a cave discovered by Earl P. Dorr and located under Kokoweef Peak. Dorr supposedly gained entry to the cave and claimed that it extended for miles, with an underground river lined with gold sediments and stalactites up to 1,500 feet long.

These locales are evidence that the Mojave Desert contains significant caves, and the lure and lore of the potential of similar finds has fueled exploration over the decades.

History of Cave Exploration in the Mojave National Preserve

Within the present day Mojave National Preserve, early discovery and exploration of caves can be attributed to Native Americans. Later, miners scoured and inhabited the area. Mines, claims, ruins, and other artifacts can be found throughout the canyons of the Preserve today.

Since the 1960s, members of the local caving community, in particular members of the Southern California Grotto, have taken an interest in the area and have documented ridgewalking activities and discoveries in grotto and regional newsletters, and other publications.

Several notable publications have become the definitive record of these explorations. These include Caves of the Providence Mountains (Quick, 1979), Report of the Providence Mountains Cave Hunt March 22 and 23, 1975, in Gilroy Canyon (Quick 1976), Caves of the Providence Mountains (Quick, 1979), and most significant for this study; Caves and Shelters in Bonanza King Canyon (September 1975 – May 1976) (Hardcastle, 1977). These contain the historical record, descriptions, and general locations of many of the caves known in the Preserve today.

In 1997, CRF expedition was held in the Preserve, including focused work in the Bonanza King Canyon area. The expedition used Hardcastle's 1975 report and Quick's 1979 report as a foundation for its activities. Several previously recorded caves were located in Bonanza King Canyon and several new small finds were added to the Mojave database (Szukalski, 2007).

Most of the early maps and records pre-date the availability and widespread use of GPS devices and digital mapping capabilities, and many of the caves and shelters are located only by general reference and rough sketch maps. Early maps of the known caves and shelters were also quite rudimentary, containing little passage detail and often only rough sketches. Other information is contained within the personal archives of cavers throughout the region.

Mojave National Preserve Cave Management

Since the inception of the Preserve in October 1994, Park planners have actively compiled information to develop a General Management Plan (GMP). The plan was published in August of 1998. The information at that time included information about Mitchell Caverns, Cave of the Winding Stair, other small caves within the local area, and the Cima lava tube (Cima Cave). The GMP noted that very little was known about the caves and an inventory was needed. Much of that information (as noted above) had already been recorded in the form of maps, trip reports, and other information that had been assembled by the local caving community, most of which was unknown at the time to the Mojave National Preserve.

In August of 1998, Ted Weasma arrived in the park to work on mining claim validity. Weasma had previous experience with cave management and inventory work while working with BLM in Boise Idaho and Roseburg Oregon, so he began to collect additional data on the cave resources of the park. In 1999, he began to collect what published data he could find in cooperation with Ron Kerbo of the NPS Denver office. Kerbo provided contact information for the Southern California Grotto in December of 1999 and the Park and local cavers have worked together since then, sharing information and leveraging the help of volunteers to collect and glean information about the historic caving record as well as new discoveries.

The park published its final GMP in 2002. The report included stipulations that the Park will:

- Manage caves in a manner that protects the natural conditions such as drainage patterns, airflow, and plant and animal communities.
- Continue to work cooperatively with the California Department of Parks and Recreation to inventory, study and protect the significant cave resources that are found at Providence Mountains State Recreation Area.
- Avoid development of caves and perpetuate natural conditions, while seeking to protect the resource.
- Develop a cave management program where significant cave resources exist.
- Enhance knowledge of cave resources through comprehensive inventory, monitoring and research.

This has been an unfunded and slow process that continues today.

In 2002, the park had 32 caves in its inventory database. Outside funding from the Association for Women Scientists became available through the Geologists in the Park

Program in 2004, and Laura Chlor came on board to do cave inventory.

Chlor developed an inventory form and worked with local cavers to gather better information on the caves in Bonanza King Canyon, with emphasis on good locality data. By 2005, with many exploration trips from local cavers (primarily members of the Southern California Grotto) 49 caves were recorded.

Currently, and with the additional information gathered via this most recent project, the Mojave National Preserve database includes 197 caves, shelters, and cave features. The longest cave in the Preserve is Warner's Cave with a length of 335 feet, though most caves are less than 100 feet long.

The Contract

In 2011, special funding became available for cave work that needed to be obligated in a very short time. The Park jumped on it as the rare opportunity to fund needed inventory work. In the initial solicitation announcement, funding was not specified but the posting listed the amount as less than $100,000.

The attractive six-figure number attracted consultants from a wide geographic area, many of whom had no previous experience or investment in caves in the Mojave National Preserve. Local cavers became concerned that the historical record would be "stepped on" and previous work and anecdotal information from decades of cavers would be lost, especially after several prospective bidders contacted local cavers for information.

The issue was brought to a satisfactory conclusion for all when MineGates, Inc., became the contract awardee. MineGates is owned by Tom Gilleland, who has a familiarity with caves in the area as well as a relationship with local cavers who have invested in looking for caves within the Preserve. MineGates assembled the winning combination for the contract award: a well-qualified team with prior experience in the Mojave and a competitive project bid. The assembled team included both volunteers and professionals, and included members of the local caving community as well as the Preserve. A total of 24 individuals contributed directly to the contracted project.

The contract work included survey, mapping, photography, and inventory in two designated areas. One area was located in the Clark Mountains, the second encompassing the heart of Bonanza King Canyon in the Providence Mountains. Field work began in December 2010, with multi-day trips and single-day excursions. Project activities were completed in March 2011.

Project Work

The master Mojave cave database is maintained in an Excel spreadsheet and includes GPS locations, jurisdiction, designations (wilderness vs. public lands), topographic quadrangle names, cave inventory notes, and other information for each cave. The two study areas were delivered to the contractor as PDF files showing the boundary of the respective study sites.

Using ArcGIS, the PDFs were rasterized and georeferenced, with the study areas digitized from each georeferenced sheet. The master Mojave database was added as a GIS layer. The study area boundaries were used to extract features within each area, thus forming the substrate for the project work. Additional data layers were used in the GIS to verify jurisdiction, quadrangle boundaries, and wilderness designation.

Additional information gleaned from sketch maps, personal communications, unpublished notes, and other sources was, where possible, placed geographically using visual review of the GIS database for field evaluation. Many of the "lost" caves and shelters in previous reports were referenced in relation to key cave locations. Once a "keystone" cave was located, other locations and historical records fell into place. By working from the original reports, the historic record and naming of cave features was preserved.

Fieldwork focused on systematic ridgewalking of the study areas, using hand-held GPS to record locations. Many of the features are located in steep canyons and are vertically stacked, thus photo locations sheets were included in the report so visual verification of features could be established when they were clustered or stacked.

The final report is 243 pages long and includes detailed notes on each cave, shelter, and feature along with photographs. The cave reports include references to information from the original source documentation. When historically recorded caves were not located, the original published information was included in the report, thus preserving the historical record for future work.

Maps of new finds and newly updated maps were included, along with original maps when updated maps were not available. The final report also included sections on biology, geology, GIS, and a comprehensive bibliography.

The longest cave included in the report was Virginia Mine Cave with a length of 131 feet. The second longest cave recorded was Wishbone Cave with a length of 80 feet. The most significant discovery biologically was the identification of Brackenridgia heroldi, previously recorded in the Mother Lode and Sequoia regions of California, and now having a significantly extended range.

Many new small caves, shelters, and other features were added to the database, bringing the total for the Bonanza King Canyon study area to 111 features.

Conclusions and Summary

Continued exploration and the significant data collection work under this contract has provided the park with a much better record of its resources. The park will continue to work with local cavers on cave exploration, inventory work, and research.

Modern and historical records, including hand-scrawled notes obtained from local cavers, were captured in the report, a key objective for local cavers involved in the project. Many new caves and shelters were documented, and formerly "lost" caves and leads were found and included in the record.

Perhaps most significantly, the volunteer efforts of generations of explorers and cavers that have invested their time, energy, and expertise to search for, map, and document caves and karst features throughout the Providence Mountains and Mojave National Preserve, was preserved.

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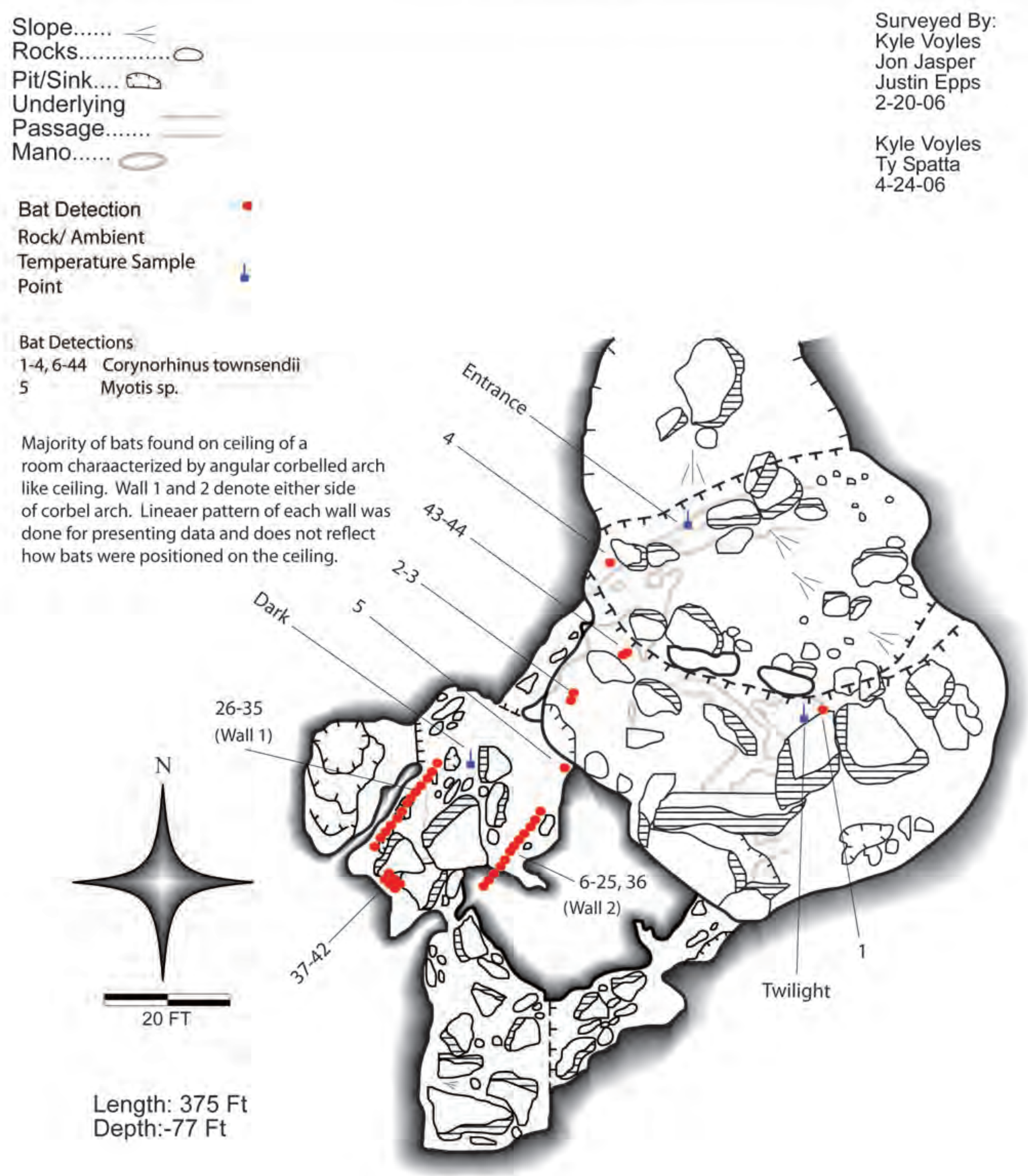
Appendix 1

Cave 1

Mohave County, AZ



Author Biographies

Tom Aley
Ozark Underground Laboratory, Inc
417-785-4289
Taley@ozarkundergroundlab.com

Tom Aley holds B.S. and M.S. degrees from the University of California (Berkeley) and is President of the Ozark Underground Laboratory. He has published extensively on cave and karst management topics, and has been a frequent presenter at national cave and karst management symposiums. He has worked extensively on management issues involving federally listed threatened and endangered species. He and his wife own Tumbling Creek Cave, a National Natural Landmark that has the most diverse cave fauna of any cave west of the Mississippi River. Much of the food input for the Tumbling Creek Cave ecosystem is gray bat guano from a large summer population.

Andy Armstrong
Timpanogos Cave National Monument
RR3 Box 200
American Fork, Utah 84003
andy_armstrong@nps.gov

Andy Armstrong works in cave and karst management for the National Park Service and is currently the Resource Management Specialist at Timpanogos Cave National Monument. Previously he has worked in cave resource management and interpretation at Jewel Cave National Monument, and Carlsbad Caverns National Park. Primarily focusing on the exploration and survey projects at Jewel Cave and Lechuguilla Cave, he and his wife Bonny are active in cave exploration and conservation throughout the Intermountain West and beyond. Andy holds a Bachelor of Science degree from East Tennessee State University, and is an instructor for the National Cave Rescue Commission.

Bonny Armstrong
Timpanogos Cave National Monument
bonnyarmstrong@gmail.com

Bonny Armstrong holds a Master's Degree in Geology from Western Michigan University and currently works as a physical science technician for the National Park Service at Timpanogos Cave National Monument. One of the duties of her position is organizing and working with volunteers on a number of cave-related projects. She herself is also involved with volunteer activities, mainly exploration and survey, at other national park units including Carlsbad Caverns National Park, Wind Cave National Park, and Jewel Cave National Monument. Bonny is a life member of the NSS and serves on the Membership Committee, the Review Committee for the American Caving Accidents publication, and assists locally and regionally with cave rescue training.

Gretchen Baker
Great Basin National Park

Gretchen Baker is the park ecologist at Great Basin National Park. She has a new appreciation for high elevation caves and wet, muddy caves after noting how much biological diversity they support.

Sandi Baker
Bigfork High School Cave Club

Sandi Baker is a junior at BHS. She works after school as an assistant chef at a French restaurant. She is also a member of the school's soccer team. Sandi has worked as a volunteer in caves in Glacier National Park, Grand Canyon National Park, and the Flathead National Forest. After high school Sandi wants to return to her home state, Alaska, to attend college.

Kevin Castle
Wildlife Health Branch
Biological Resource Management Division
National Park Service
970-267-2162

Kevin Castle is a veterinarian with the Wildlife Health Branch of the NPS Biological Resource Management Division, headquartered in Ft. Collins, CO. As one of four wildlife veterinarians in the NPS, Kevin works with parks and regions nationwide to preserve and improve the health of wildlife populations, by providing professional and technical assistance regarding animal health and welfare issues, zoonotic diseases, disease outbreak investigations, and training for park staff. Kevin has been with the NPS since March 2008, and has been working on white-nose syndrome since day one. Kevin is the NPS technical lead for white-nose syndrome, and has participated in Congressional briefings, National Plan development, and NPS white-nose syndrome working group coordination.

BJ Cluff
Timpanogos Cave National Monument
RR3 Box 200
American Fork, Utah 84003
BJ_Cluff@nps.gov

BJ Cluff has worked for Timpanogos Cave Nat'l Monument for 14 seasons, where she was introduced to caving by other co-workers in 1990. She has worked in the resource management division as a physical science tech, and in her current position as an Interpretive Ranger. In that time, she has worked on resource monitoring and cave restoration projects. For her free time, she enjoys hiking and backpacking. She is currently pursuing a Bachelor of Science degree at Utah Valley University, majoring in Earth Science with an emphasis in Environmental Management. Outside of work and school, she volunteers with multiple youth groups to educate and guide positive change.

Jeremy Coleman
US Fish & Wildlife Service
Jeremy_Coleman@fws.gov

Jeremy Coleman is the Northeast Regional Wildlife Disease Coordinator for the US Fish and Wildlife Service, and is the National Coordinator for White-Nose Syndrome. He holds a MS and
PhD in wildlife ecology from Cornell University and has been working on white-nose syndrome since starting with USFWS New York Field Office in February 2008. Jeremy is currently located at the USFWS Northeast Regional Office in Hadley, MA.

Joseph Fagan
Joseph Fagan and Associates
403 Franklin Drive
Blacksburg, Virginia 24060
joseph.fagan.and.associates@gmail.com

Joseph (Joey) Fagan earned his B.A. in Geography with a minor in Geology in 1976 from Emory and Henry College and studied Geography and Geology in graduate school at Virginia Tech during the early 1980's. Joey works as a karst hydrologist and environmental planning consultant for localities in cooperation with various state and federal agencies and NGOs. He was a Karst Protection Specialist for the Virginia DCR Natural Heritage Program from 2001 through 2009. Joey started caving in 1966; he is a member and Fellow of the National Speleological Society (NSS). He is a founding member of Blue Ridge Grotto, a life member of the VPI Cave Club, and a member of the NSS Geology and Geography, Cave Conservation and Management, and Vertical Sections. He is NSS Youth Group Caving Coordinator for the Virginia Region. Joey serves on the Cave Conservancy Foundation and the Cave Conservancy of the Virginias Boards.

Karissa DeCarlo
Timpanogos Cave National Monument
RR3 Box 200
American Fork, Utah 84003
Karissa_DeCarlo@nps.gov

Karissa DeCarlo has worked for the National Park Service since 2001. Currently, she is the supervisory interpreter at Timpanogos Cave Nat'l Monument, overseeing the rangers leading visitors on cave tours. She has been a ranger at Mt. Rushmore Nat'l Memorial, Wright Brothers Nat'l Memorial, Cape Hatteras Nat'l Seashore, Lewis and Clark Nat'l Historic Trail, and the Statue of Liberty Nat'l Monument. Her education includes a BS in Environmental and Sustainable Resources from the University of Louisiana at Lafayette and a MS in Parks, Recreation and Tourism from West Virginia University. As a ranger, her duties include program planning, designing signs and exhibits, managing a staff of nearly 30, and producing park publications. In her spare time she enjoys practicing yoga and visiting National Parks.

Lee Florea
Department of Geological Sciences
Ball State University
813-784-849
mr_chaos@hotmail.com

Lee J. Florea is an Assistant Professor of Geology at Ball State University and a registered professional geologist in Kentucky and Indiana. Lee earned his PhD in Geology from the University of South Florida where he produced a dissertation titled "The Karst of West-Central Florida" in 2006. Following his dissertation, he spent two years as a Mendenhall Postdoctoral Fellow for the US Geological Survey in Ft. Lauderdale where he began his investigations into stable isotopes. An avid cave cartographer, founding president of the Kentucky Speleological Survey, and a fellow of the National Speleological Society, Lee has explored and published studies on the caves and karst of Kentucky for more than fifteen years.

Shane Fryer
Lava Beds National Monument

Shane Fryer is currently the Physical Scientist at Lava Beds National Monument. He has worked with cave resources within the National Park Service for over a decade, spending five years at Sequoia-Kings Canyon National Park and is now in his sixth year at Lava Beds. As a component of his undergraduate work at Western Kentucky University, he spent three years interning/volunteering with five cave parks including Jewel Cave, Wind Cave, and Mammoth Cave. Shane has now participated in 14 international cave expeditions including Guatemala, Cuba, Indonesia, and China. While in the states he is still active in caving projects back in Kentucky and in the western U.S.

Anthony Gallegos
Utah Abandoned Mine Reclamation Program
1594 West North Temple
Salt Lake City, Utah 84114
801-538-5267
anthonygallegos@utah.gov

Anthony A. Gallegos has worked in the AMRP eleven years as a Reclamation Engineer managing mine closure projects from the inventory and engineering phase through NEPA compliance to construction completion. My other duties include coordinating underground bat surveys and managing the radiation health and safety plan. Previously I worked in the Utah regulatory program for hardrock mining for ten years reviewing mining and reclamation plans, reclamation bonding, performing site inspections and coordinating mine permitting with other state and federal agencies. My educational includes an MS, and BS in Mining Engineering from the University of Utah. I have been an instructor for the University of Utah teaching courses in their Natural Resource Learning program since 1990. When I am not working I enjoy whitewater boating, bicycling, triathlons, cross country skiing, diving and most any other outdoor fun.

Tom Gilleland
MineGates, Inc.
4980 N Campbell Ave.
Tucson, AZ 85718
520-577-8945
tom@minegates.com

Tom Gilleland of MineGates Inc designed and installed scores of bat-friendly cave and mine gates for US Forestry, National

Parks, BLM and private cave and mine owners. He is the founder and Co-owner of the Cathedral Cave Preserve (cathedralcave.org). Founder of the Arizona Cave Survey (arizonacaves.org). He has been an active caver for over 30 years, visited thousands of caves and mines in 20 US states and nine countries. He has extensive knowledge of caves and mines throughout the US, and especially the Western states of Arizona, New Mexico, Nevada, and California. He also has extensive experience working on cave and mine projects including archaeological, paleontological, biological, inventory and survey work.

Jim Goodbar
BLM Carlsbad Field Office

Elizabeth Hale
Oregon Caves National Monument
Elizabeth_Hale@nps.gov

Elizabeth Hale is a GIS Specialist at Oregon Caves National Monument, where she has been working in resource management since 2005.

Kimberley Hersey

Kimberly Hersey is a sensitive species biologist with the Utah Division of Wildlife Resources specializing in non-game birds and mammals. She currently serves as chair of the UBCC. She received her undergraduate training at Wittenberg University and her master's degree in wildlife biology from The University of Tennessee.

Greg Horne
Jasper National Park
Box 10
Jasper, Alberta, T0E 1E0, Canada

Greg Horne's 32 year career with Parks Canada began as interpretive planner then primarily was a Park Warden and more recently evolved to a Resource Management and Visitor Safety Specialist. Currently his core job duties relate to backcountry ecological monitoring. Duties related to cave management commenced in 1995 and the primary focus has been Jasper National Park and along with Castleguard Cave in Banff National Park. He has presented papers at three previous NCKMS events. His passionate ongoing cave project is the exploration, inventory and mapping of a cave in Jasper National Park called the Ice Trap over the past 8 years.

Rodney Horrocks
Wind Cave National Park
605-745-1158
Rod_Horrocks@nps.gov

Jon Jasper
jon@jonjasper.com

Jon Jasper is an Outdoor Recreation Planner for the BLM Arizona Strip Field Office stationed in St George, Utah. Previously Jon has worked as a Cave Specialist for BLM Carlsbad Field Office, Timpanogos Cave National Monument, and Great Basin National Park.

Patricia Kambesis
Hoffman Environmental Research Institute
Western Kentucky University

Pat Kambesis is an experienced cave explorer and karst scientist who has work nationally and internationally on cave documentation projects, cave and karst research, and cave and karst management issues and concerns.

James Kaufman
Earth Resources Observation and Science Center
U.S. Geological Survey
573-578-893
jkaufmann@usgs.gov

Jim Kaufmann is a research physical scientist with the U.S. Geological Survey's Earth Resources Observation and Science Center (EROS). Jim has many years of experience in cave and karst conservation and research and was co-chair of the 2007 NCKMS which was held in St. Louis, Missouri. Prior to working for the USGS he was the resident cave ecologist for the Missouri Department of Conservation and had spent several years prior to that building cave gates.

Jim Kennedy
Bat Conservation International
Post Office Box 162603
Austin, TX 78716-2603
jkennedy@batcon.org
512-327-9721

Jim Kennedy is a conservation biologist (Habitat Protection Coordinator) and educator at Bat Conservation International in Austin, Texas. He has a MEd in Biology with an emphasis in Environmental Education. He is the Bat/Cave Liaison for Cave Conservation and Management Section of the National Speleological Society, and represents BCI on the Steering Committee of the National Cave and Karst Management Symposium. He has studied caves throughout the United States, Mexico, Panama, Venezuela, Belize, and the Philippines. He has been working with bats and bat habitat since 1994, specializing in artificial roosts, cave and mine hibernacula, roost microclimates, cave management, abandoned mine assessment, and cave and mine gating. Besides advising Federal and State land managers on cave and karst inventory and protection methods, he helps lead cave gating workshops around the country. He is a Life Member and Fellow of the National Speleological Society, and previously Chair of the Mid-Appalachian Region of the NSS, Chair of the Texas Speleological Association, Editor of the Texas Speleological Survey, and Director of the Texas Cave Management Association.

Johanna Kovarik
P.O. Box 19001
Thorne Bay, Alaska 99919
907-828-3224
jkovarik@fs.fed.us

Johanna Kovarik is a geologist and karst resource specialist on the Tongass National Forest in southeast Alaska, with a Master of Science from Western Kentucky University. Johanna is currently working on her PhD in Environmental Science and Policy from the University of South Florida, with a dissertation project involving cave and karst management in Chiapas, Mexico. Her research and management work focuses on protection of subsurface aquifers, particularly in areas of karst development. In her spare time, Johanna is an avid caver, leading expeditions in southeast Alaska and participating globally in cave exploration and karst resource work with the US Forest Service, Hong Meigui Exploration Society, Cave Research Foundation, National Speleological Society, and others.

Jean Krejca
Zara Environmental LLC

Dr. Jean Krejca has a Bachelor's degree in Zoology, and a Ph.D. in Evolution, Ecology and Behavior from the University of Texas at Austin. Her dissertation work focused on cave adapted aquatic fauna, biogeography and hydrology of Texas and North Mexico. Since 1991 she has worked as a cave biologist and her experience in that area spans across the United States (Arkansas, California, Texas, Nevada, Illinois, Missouri, Indiana, Tennessee, North and South Carolina) as well as Mexico, Belize, Thailand and Malaysia. In 2003 she co-founded Zara Environmental LLC where she continued her work from independent consulting and expanded to perform land management for landowners with endangered species, consult on endangered species permits, and perform custom research projects. In addition she has been involved with a variety of public outreach efforts such as public talks, field trips, and cave biology photography.

Katie LaFeaver
Bigfork High School Cave Club

Katie LaFeaver is a junior at BHS. She holds down two afterschool jobs, one as an assistant chef at a pizzeria and the other as a maintenance assistant and groundskeeper for a home community association. Katie has worked as a volunteer in caves in Glacier National Park and Flathead National Forest. After high school Katie wants to study to become a hospice nurse.

Adam Leavitt

Adam Leavitt first started caving at age 6 in Utah's popular Nutty Putty Cave. It is ironic that he was one of the final cavers entering the cave as part of the caving death rescue/recovery team before its closure. Now at age 17, Adam has developed skills in vertical caving and has led several trips through local caves. As a Boy Scout since age 11, Adam was excited to take on the Spanish Moss photo logging project in his final step to attaining his Eagle Scout Award. Adam is very athletic and also a talented singer and stage performer. Only the passing of time will reveal where Adam's future college and life experiences will lead. One thing is for certain and that is Adam will have a fun-loving life full of music, stage, and outdoor experiences.

Michael Leavitt

Michael Leavitt has been a caver since 1992 and the most recent Cave Access Manager of the now permanently closed Utah Nutty Putty Cave due to the well-publicized November 2009 death in the same cave. In his professional life, Michael is a long time home inspector and national speaker, author, and spokesperson on Home Inspection industry issues. Michael is also a skilled website designer and maintains over 50 business, personal, and non-profit websites. Michael is married to his lovely wife, Shelly, and enjoys being a father to his 4 great kids (3 of which also love caving), while doing his best adapting to the new role of Grandpa to twins. At 6'6" and 220 pounds, Michael is the last person you would expect to cram himself through incredibly tight passages, but he loves the subterranean adventure.

Benjamin Miller
Department of Geology and Geography
Western Kentucky University

Ben Miller is an Environmental Research Specialist for the Hoffman Environmental Research Institute and Crawford Hydrology Laboratory. Ben currently leads the field and laboratory crew researching agricultural impacts and contaminant transport in karst areas in collaboration with the US Department of Agriculture. Ben has also support Hoffman research projects in the areas of cave survey, cave restoration, and development of cave management plans and has worked internationally on projects in Haiti, Puerto Rico, and Belize. Ben is a prolific cave surveyor and documenter, actively working with both state and national caving organizations. Prior to working for Western Kentucky University, Ben specialized in cave resource management, karst education, and karst hydrology while working for the National Park Service at Jewel Cave National Monument and Lava Beds National Monument as well as for five years at Missouri's Onondaga Cave State Park.

Dale Pate
Carlsbad Caverns National Park

Dale Pate is currently the Cave Specialist (Supervisory Physical Scientist) at Carlsbad Caverns National Park and also is the lead Cave and Karst Program Coordinator for the national-level Geologic Resources Division within the National Park Service.

Jason Polk
Hoffman Environmental Research Institute
Western Kentucky University
1906 College Heights Blvd.
Bowling Green, KY 42101
270-745-5015
jason.polk@wku.edu

Jason S. Polk, Ph.D. is the Associate Director of Science for the Hoffman Environmental Research Institute and an Assistant Professor of Geography and Geology at Western Kentucky

University. He earned his doctorate degree from the University of South Florida in Geography and Environmental Science and Policy, where his research focused on karst speleogenesis, climate change, and water resources. Dr. Polk's current research investigates the geomorphology and hydrology (including water quality) of karst environments, isotope geochemistry, karst resource inventory and management, and the influence of climate change on paleohydrology. He has published over 30 peer-reviewed papers and abstracts, is a Fellow of the National Speleological Society, and is Vice President of The Karst Conservancy. He is also a member of the Geological Society of America, American Geophysical Union, International Association of Hydrogeologists, and Association of American Geographers.

Rene Ohms
Jewel Cave National Monument
Rene_Ohms@nps.gov

Rene Ohms is a physical science technician for the National Park Service at Jewel Cave National Monument, South Dakota. During her career with the NPS, she has been an interpreter, fire effects monitor, and, for the last 12 years, a resource manager specializing in cave management. She maintains the Jewel Cave rescue cache and coordinates cave rescue operations for the park, and is a National Cave Rescue Commission instructor. Rene has been a caver for 16 years and particularly enjoys project caving and survey. She holds a Bachelor of Science degree in Biology from the University of Arizona, and has continued graduate education in Geographic Information Systems.

Emily Ring
Oregon Caves National Monument
541-592-2100 x 2254
emily_ring@nps.gov

Emily Ring is currently pursuing her Master's in Conservation Biology and is a Physical Science Technician with the Oregon Caves National Monument. Physical data collection for this project was supported by Southern Oregon University undergraduate Heather Bailey. Prior natural resource experiences for Ms. Ring include anadromous fish studies, wildlife inventory, riparian restoration and related hydrobiology work.

Ben Roberts
Great Basin National Park
775-234-7331 x 228
ben_roberts@nps.gov

Ben Roberts is currently the Chief of Natural Resource Management at Great Basin National Park. He has been involved in numerous park cave projects over the past 10 years.

Miriam Toro-Rosario
787-300-0602
tororosa@msu.edu

Miriam Toro-Rosario was born in Santurce, Puerto Rico and completed her K-12 studies in several schools in the metropolitan cities of San Juan and Trujillo Alto. In January 2011, Miriam graduated from the Environmental Science program at the University of Puerto Rico, Río Piedras Campus, and completed an undergraduate thesis dealing with the ecology of cave-dwelling insects in several caves systems in Puerto Rico. She is a current member of a number of local and international organizations like the Marine Environment Society, Puerto Rican Karst Speleological Research Foundation, The Conservation Trust of Puerto Rico, Ecological Society of America, Audubon Society, Organization for Tropical Studies, International Union of Speleology, Czech Speleological Society, and Critical Mass Dortmund in Germany. Miriam has recently enrolled in the Master's program of the department of Fisheries and Wildlife at the Michigan State University, specializing in Environmental Public Policy in tropical karst systems. Her main professional goal is to advocate and contribute to the public policy making of karst resources in Puerto Rico.

Dawn Ryan

Dawn Ryan's caving career started about 11 years ago when visiting a commercial cave in Wisconsin. In those 11 years of caving since, Dawn has led cave surveys and cave adapted invertebrate inventories. Over the years she has served as the membership committee chair for the National Speleological Society and has been awarded a fellow of the Society as well as the e Cave Research Foundation. Dawn is also a permanent interpretative ranger at Sequoia National Park working at that park for five years while working on completing a degree at Oregon State University in natural resources management.

Brennen Shaw
Bigfork High School Cave Club

Brennen Shaw is a senior at BHS. He works as a mechanic at his father's auto repair and tire shop. As a member of the Cave Club, Brennen has worked as a volunteer in caves in Glacier National Park, Grand Canyon National Park, Flathead National Forest, Lincoln National Forest, and Lewis and Clark National Forest. Next year Brennen plans to attend college at Montana State University to study mechanical engineering.

Katrina Smith
Lavabeds National Monument

Katrina Smith works as a Student Conservation Association Cave Management Intern at Lava Beds National Monument in northern California. She assists with a variety of projects within the Resource Management Division, including white-nose syndrome response efforts and bat monitoring, database management, and public education. She recently graduated from the University of Wisconsin-Eau Claire with a B.S. in Ecology and Environmental Biology and moved west to pursue her internship at Lava Beds. Her time there has contributed greatly to her knowledge of bat ecology and allowed her to further explore her interest in caving.

Michael Slay
Arkansas Field Office
The Nature Conservancy
601 North University Avenue
Little Rock, AR 72205 USA
479-973-9110
mslay@tnc.org

Michael Slay has been working on karst conservation issues for ten years with much of his work occurring in the Ozark Highlands Ecoregion. Before joining The Nature Conservancy as the Ozark Karst Program Director, Mike coordinated karst research during positions held at University of Arkansas, Buffalo National River NPS, Illinois Natural History Survey, and Missouri Department of Conservation. Since joining The Nature Conservancy, Mike has worked with multiple partners such as US Fish and Wildlife Service, US Forest Service, Arkansas Game and Fish Commission, Missouri Department of Conservation, Oklahoma Biological Survey, and Illinois Natural History Survey to conserve and protect karst species and habitats. Mike has coordinated the exploration, species monitoring, and habitat analysis in several hundred caves and springs, and he has assisted with the discovery of over 15 karst species new to science. Mike received his undergraduate degree and M.S. in Biology at the University of Arkansas.

Lawerence Spangler
U.S. Geological Survey
2329 Orton Circle
Salt Lake City, Utah 84119

Larry Spangler has been employed as a groundwater hydrologist with the U.S. Geological Survey in Salt Lake City since 1988. He received an M.S. degree in geology from the University of Kentucky in 1982, with thesis work on the karst hydrology of the Inner Bluegrass Region in central Kentucky. After graduate school, Larry worked for a geological consulting company in Denver, Colorado, as a carbonate petrologist. Shortly after moving to Utah, he began karst hydrology studies in the Bear River Range in northern Utah to delineate groundwater flow systems using dye-tracing methods and has continued these studies to the present time. Larry has also conducted hydrologic studies of an alpine karst system on the Markagunt Plateau in southwestern Utah. Larry joined the NSS in 1974, has been Chair of the Wasatch and Salt Lake Grottos, and is an instructor in karst hydrology/geomorphology in the Speleology for Cavers short course at NSS Conventions.

Bernard Szukalzki
ESRI
380 New York Street
Redlands, CA 92373 USA
909-793-2853 ext. 1315
bszukalski@esri.com

Bernard Szukalski has a degree in biology and chemistry, and has held a variety of positions during the last 25 years at Esri, the leading Geographic Information System (GIS) and digital mapping company where he is a senior staff member, product strategist, and evangelist. He is also Esri's cave and karst industry manager, and is a certified GIS professional (GISP).~ 13 ~ Szukalski has been a member of the National Speleological Society and has been involved in organized caving since 1976. He has served on the board of directors of the National Speleological Society (NSS), Cave Research Foundation (CRF), Hawaii Speleological Survey (HSS), American Cave Conservation Association (ACCA), and Pennsylvania Cave Conservancy (PCC). He is a fellow of both the Cave Research Foundation and National Speleological Society. Szukalski currently serves on the Board of Directors of the Cave Research Foundation and holds the position of secretary.

Steven Taylor
Illinois Natural History Survey
University of Illinois
1816 S. Oak St.
Champaign, IL 61820

Steve Taylor is a biospeleologist interested primarily in cave & karst biology, conservation and management. His research focuses on subterranean ecosystem structure and function, human impacts on subterranean ecosystems at a variety of scales from landscape level to site-specific impacts, considerations in cave and karst preserve design in relation to cave ecosystems, and subterranean biodiversity and knowledge gaps.

Shawn Thomas
Lava Beds National Monument
530-667-8150
shawn_thomas@nps.gov

Shawn Thomas works as a Physical Science Technician at Lava Beds National Monument in northern California, where he has been stationed since 2009. He is part of the cave management program at Lava Beds and supports a variety of projects in the Resource Management Division. Shawn's primary focus is on bat monitoring and bat management, and he serves as the monument's representative in collaborating with agencies and researchers on white-nose syndrome and bat research. Shawn has been employed with the National Park Service (NPS) since 2005, and prior to arriving at Lava Beds, he worked at four other NPS cave parks. Shawn is also a caver and has been involved with cave exploration and other caving projects in the western U.S. for nearly a decade.

Sarah Truebe
650-804-5413
struebe@arizona.edu

Sarah Truebe, NSS #61563, grew up in Tucson, Arizona, where she learned to observe the world from her parents (a geologist/caver (NSS #5071) and an archaeologist). Growing up with saguaros, she also learned to love the Sonoran Desert and the North American monsoon. Pursuing these interests, she went to Stanford University to major in Earth Systems (interdisciplinary earth science and policy). She received a Master's in Earth Systems from Stanford as well. Then, she was a research assistant in a lab focused on the end-Permian mass extinction, during which >90% of all marine life went extinct. This experience provided vital perspective on more recent environmental change, which Sarah now studies using cave speleothems from southern Arizona as a PhD student at the University of Arizona. When not researching, Sarah plays piccolo with the UA Wind Ensemble, volunteers with the Southern Arizona Rescue Association, and explores Tucson's fine mountains (above and below ground)!

George Veni
National Cave and Karst Research Institute
400-1 Cascades Avenue
Carlsbad, New Mexico 88220-6215 USA
gveni@nckri.org

Dr. Veni is an internationally recognized cave and karst hydrogeologist. Prior to NCKRI, he owned and served as principal investigator of George Veni and Associates for more than 20 years. He has conducted extensive karst research throughout the United States and in several other countries. His administrative work includes serving as the Executive Secretary of the National Speleological Society's Section of Cave Geology and Geography for 11 years, President of the Texas Speleological Survey for 13 years, Adjunct Secretary of the Union Internationale de Spéléologie (UIS) from 2002-2009, and UIS Vice President of Administration since 2009. He has served as a committee member of geological, geographical, and biological dissertations at The University of Texas and Harokopio University (Greece), and taught karst geosciences courses for Western Kentucky University for 12 years. He has published and presented over 180 papers and five books, on hydrogeology, biology, and environmental management in karst.

Cyndee Watson
Austin Ecological Services Office
U.S. Fish and Wildlife Service
Cyndee_Watson@fws.gov

Cyndee Watson earned her B.A. in Geography with a minor in Zoology from the University of Texas at Austin in 2002. That same year she entered Texas State University-San Marcos where she completed her Master's thesis on estimating the probability of detecting golden-cheeked warblers. While in graduate school, she started her career at the U.S. Fish and Wildlife Service as a wildlife biologist working to recover endangered karst invertebrates where she still is today.

Jason Walz
Lincoln National Forest
US Forest Service

Jason Walz accepted his current position, Cave Specialist, with Lincoln National Forest in June of this year after working for the NPS for 12 years. During his NPS years, he spent 9 years working in cave management at Wind Cave National Park and one year at Carlsbad Caverns National Park.

Mike Wiles
Jewel Cave National Monument
11149 U.S. Highway 16 #B12
Custer, SD 57730
Mike_Wiles@nps.gov

Mike Wiles was born in Huron, S.D. in 1956. Twenty years later, he was introduced to caving by members of the Paha Sapa Grotto, of the National Speleological Society, then a student grotto at South Dakota School of Mines and Technology. Since then, he has volunteered more than 7,000 hours toward the exploration of Jewel Cave. He holds a B.S. in Chemical Engineering and an M.S. in Geological Engineering, both from SDSM&T. His 1992 Master's thesis is entitled, "Infiltration [of groundwater] at Wind and Jewel Caves, Black Hills, South Dakota. Mike has worked at Jewel Cave National Monument for over 30 years, first as Interpretive park ranger, then as a Cave Specialist, and is currently the Chief of Resource Management for the park.

Carol Zokaites
National Coordinator of Project Underground
Environmental Education Manager for the Virginia Department of Conservation and Recreation
540-382-5437
czokaite@vt.edu

Carol Zokaites started caving in 1973 while attending Virginia Tech. She has participated in many cave mapping and karst conservation projects. Zokaites has helped create several karst publications including "Living on Karst," and the Project Underground Activity Guide and has authored many papers on cave and karst education. She is now the National Coordinator of the karst education program - Project Underground and the Environmental Education Manager for the Virginia Department of Conservation and Recreation. Carol Zokaites has a B.S. in Forestry and Masters of Arts in Education from Virginia Tech. She is a fellow of the National Speleological Society and has the received the National Speleological Society's Conservation award.

Participant List

Charles M Acklin
VOLTI
PO Box 518
Heber City, UT
435-901-8360
cma@byvolti.com

Tom Adams
Petzl
tadams@petzl.com

Tom Aley
Ozark Underground Laboratory
1572 Aley Lane
Protem, MO 65733
417-785-4289
Taley@ozarkundergroundlab.com

Andy Armstrong
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003
801-492-3647x502
Andy_Armstrong@nps.gov

Bonny Armstrong
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003
480-861-1807
bonnyarmstrong@gmail.com

Gretchen Baker
Great Basin National Park
100 Great Basin National Park
Baker, NV 89311
775-234-7331 x251
gretchen_baker@nps.gov

Sandi Baker
Bigfork High School
1120 4th Ave. West
Kalispell, MT 59901

Susan Baughman
USFS Dixie National Forest
2119 N Sawmill
Cedar City, UT 84721
435-865-3703
sbaughman@fs.fed.us

Jenny Beeler
Cumberland Gap NHP
91 Bartlett Park Rd
Middlesboro, KY 40965
606-246-1113
Jenny_Beeler@nps.gov

Hans Bodenhamer
Bigfork High School
PO 188
Bigfork, MT 59911
406-837-7420
hansb@bigfork.k12.mt.us

Kristen Bromley
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003

Radim Capek
Tomas Bata University

Kevin Castle
National Park Service
Kevin_Castle@nps.gov

BJ Cluff
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003

Jeremy Coleman
U.S. Fish and Wildlife Service
607-753-9334
Jeremy_Coleman@fws.gov

Shane Coles
National Speleological Society
801-893-1270
caverman@ymail.com

Ernie Cottle
Bigfork High School
1120 4th Ave. West
Kalispell, MT 59901

Drew Crane
U.S. Fish and Wildlife Service
Drew_Crane@fws.gov

Sue Crowl –Bromley
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003

Karissa DeCarlo
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003
801-756-5239
Karissa_DeCarlo@nps.gov

Richard L Downey
Timpanogos Grotto
380 N 600 E
Orem, UT 84097
801-224-6678
cavediva@msn.com

Thom Engel
Northeastern Cave Conservancy
16 Equinox Ct #2A
Delmar, NY 12054
518-478-9664
necaver@earthlink.net

Joseph H Fagan
Joseph Fagan and Associates
403 Franklin Drive
Blacksburg, VA 24060540-953-1643
joey_fagan@yahoo.com

Lee Florea
Ball State University
lflorea@bsu.edu

Shane Fryer
Lava Beds National Monument
shane_fryer@nps.gov

Anthony A Gallegos
State of Utah, Abandoned Mines Reclamation Program
Utah Div of Oil, Gas, and Mining
1594 W N Temple
Salt Lake City, UT 84114
801-538-5267
anthonygallegos@utah.gov

Kelly Gallo
Soldier Hollow Charter School
TeachingGreen@yahoo.com

Tom Gilleland
MineGates
4980 N Campbell Ave
Tucson, AZ 85718
520-577-8945
Tom@minegates.com

Kyle Gochenour
National Speleological Society
634 Fairmont Dr.
Macon, GA 31210
Kyle.Gochenour@gmail.com

James Goodbar
Bureau of Land Management
620 E Greene St
Carlsbad, NM 88220
575-234-5929
James_Goodbar@blm.gov

Mike Gosse
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003
801-756-5239 x201
Michael_Gosse@nps.gov

Dale Green
Salt Lake Grotto
4230 Sovereign Way
Salt Lake City, UT 84124
801-277-6417
pakrat7j@burgoyne.com

Elizabeth Hale
Oregon Caves National Monument
Elizabeth_Hale@nps.gov

Melissa Hendrickson
Ashley National Forest
355 N Vernal Ave
Vernal, UT 84078
435-781-5137
mrhendrickson@fs.fed.us

David Herron
Ashley National Forest
85 W Main
PO Box 981
Duchesne, UT 84021
435-781-5218
daherron@fs.fed.us

Kimberly Hersey
Utah Division of Wildlife
kimberlyasmus@utah.gov

Val Hildreth-Werker
National Speleological Society – Conservation Division
Cuna Cueva HWY 27
PO BOX 207
Hillsboro, NM 88042
575-895-5050
werks@cunacueva.com

Greg Horne
Parks Canada, Jasper National Park
Box10
Jasper, Alberta
T0E 1E0 Canada
780-852-6259
greg.horne@pc.gc.ca

Rodney D Horrocks
Wind Cave National Park
26611 US Hwy 385
Hot Springs, SD 57747
605-745-1158
Rod_Horrocks@nps.gov

Tommy Inebnit
USFWS, Arkansas ES Field Office
110 S Amity Rd, Suite 300
Conway, AR 72032
501- 513-4483
thomas_inebnit@fws.gov

Jim Ireland
National Park Service
RR 3 Box 200
American Fork, UT 84003
801-756-5239
jim_ireland@nps.gov

Roberta Jacobsmeyer
Bonneville Elementary
jacor117@alpine.k12.ut.us

Jon Jasper
BLM Arizona Strip Field Office
jon@jonjasper.com

Jack Johnson
Amistad NRA
4121 hWY 90 West
Del Rio, TX 78840
830-775-7491 x217
jack_g_johnson@nps.gov

Pat Kambesis
Cave Research Foundation
Western Kentucky University
pat.kambesis@wku.edu

James Kaufmann
United States Geological Survey
jkaufmann@usgs.gov

Ray Kelsey
BLM Salt Lake Field Office
2370 S 2300 W
Salt Lake City UT 84119
801-977-4300
rkelsey@blm.gov

Jim “Crash” Kennedy
Bat Conservation International
PO Box 162603
Austin, TX 78716
512-327-9721
jkennedy@batcon.org

Dan “Dante” Kleinman
514 Americas Way #3053
Box Elder, SD 57719
718-208-3757
dskleinm@gmail.com

Jason Knight
MineGates
545 W 450 E
Payson UT, 84651
801-380-3550
caveutah@gmail.com

Johanna Kovarik
US Forest Service
jkovarik@mail.usf.edu

Jean K Krejca
Zara Environmental LLC
1707 W FM 1626
Manchaca TX, 78652
512-291-4555
jean@zaraenvironmental.com

Katie Lafeaver
Bigfork High School
1120 4th Ave. West
Kalispell, MT 59901

Adam Leavitt
Timpanogos Grotto
Adam@AtomicAdam.com

Michael Leavitt
Timpanogos Grotto
Michael@TheHomeInspector.com

Cami Lee
39 S 800 E
American Fork, UT 84003
801-602-1869

Eathan McIntyre
Grand Canyon Parashant National Monument
eathan_mcintyre@nps.gov

Cami McKinney
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003
801-492-3647x501
Cami_McKinney@nps.gov

Ben Miller
WKU Hoffman Institute
benjamin.miller@wku.edu

Jan Morse
Utah Division of Oil, Gas, Mines.
Abandoned Mine Reclamation Program
1594 W. North Temple, Suite 1210
Box 145801
Salt Lake City, UT 84114
801-538-5327
janmorse@utah.gov

Rene Ohms
Jewel Cave National Monument
11149 US HWY 16 #B12
Custer, SD 57730
605-673-8310
Rene_Ohms@nps.gov

Dale Pate
National Park Service
3225 National Parks HWY
Carlsbad, NM 88220
575-785-3107
dale_pate@nps.gov

Barbara Pitman
US Forest Service
Beartooth Ranger District
6811 HWY 212
Red Lodge, MT 59068
406-446-2103
bpitman@fs.fed.us

Chris Plunkett
Ashley National Forest
355 N Vernal Ave
Vernal, UT 84078
435-781-5140
cplunkett@fs.fed.us

Emily Ring
Oregon Caves National Monument
19000 Caves HWY
Cave Junction, OR 97523
541-415-2844
emily_ring@nps.gov

Ben Roberts
Great Basin National Park
Ben_Roberts@nps.gov

Luisa Rosado-Seijo
Conservation Trust of Puerto Rico
dupreed@fideicomiso.org

Miriam Toro Rosario
Michigan State University
Fundacion de Investigaciones Espelogicas del Karso Puertorriqueno
1547 N Hagadorn Rd
East Lansing, MI 48823
mtierrapr@gmail.com

Dawn Ryan
National Park Service
PO Box 255
Sequoia National Park
CA 93262
815-260-3454
Dawn_Ryan@nps.gov

Cynthia Sandeno
U.S. Forest Service
Cmsandeno@fs.fed.us

Luisa Rosado Seijo
The Conservation Trust of Puerto Rico
PO BOX 9023554
San Juan, PR 00902
787-722-5834
rosadol@fideicomiso.org

Brennan Shaw
Bigfork High School
1120 4th Ave. West
Kalispell, MT 59901

Andrew Simister
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003

Michael Slay
The Nature Conservancy
mslay@tnc.org

Vicki Snitzler
Oregon Caves National Monument
19000 Caves HWY
Cave Junction, OR 97523
541-592-2100
Vicki_Snitzler@nps.gov

Charles Snowden
Timpanogos Cave National Monument
RR 3 Box 200
American Fork, UT 84003

Larry Spangler
U.S. Geological Survey
spangler@usgs.gov

Debbie Spoons
Timpanogos Grotto
801-808-8180
ddspoons@yahoo.com

Aaron Stover
National Park Service
4497 SW Bowsprit Dr.
Lee's Summit, MO 64082
816-537-7811
astover45@yahoo.com

Val Stratford
National Speleological Society
ms_dragonfly@xmission.com

Bern Szukalski
Esri
bszukalski@esri.co,

Steven J Taylor
Illinois National History Survey, Univ. of Illinois
1816 S Oak St.
Champaign, IL 61820
sjtaylor@illinois.edu

Shawn Thomas
Lava Beds National Monument
PO Box 1240
Tulelake, CA 96134
530-667-8150
shawn_thomas@nps.gov

Sarah Truebe
University of Arizona
1040 E 4th St.
Gould-Simpson Bldg # 77 RM 208
Tucson, AZ 85721
650-804-5413
Struebe@arizona.edu

Eugene Vale
Missouri State Parks
46 Cedar Dr.
Pacific, MO 63069
636-667-4164
eugene.vale@dnr.mo.gov

George Veni
National Cave and Karst Research Institute
400-1 Cascades Ave
Carlsbad, NM 88220
575-887-5517
gveni@nckri.org

Jason Walz
Lincoln National Forest
114 S Halagueno St
Rm 159
Carlsbad, NM 88220
575-885-7426
jawalz@fs.fed.us

Michael Warner
NCKMS
PO Box 10
Schoharie NY 12157

Cyndee Watson
U.S. Fish and Wildlife Service
10711 Burnet Rd. #200
Austin, TX 78758
512-490-0057 x223
cyndee_watson@fws.gov

Jim Werker
National Speleological Society – Conservation Division
Cuna Cueva HWY 27
PO BOX 207
Hillsboro, NM 88042
575-895-5050
jimwerker@zianet.com

Mike Wiles
Jewel Cave National Monument
11149 US HWY 16
Custer, SD 57730
605-673-8308
Mike_Wiles@nps.gov

Tony Wright
Utah Division of Wildlife Resources
319 N Carbonville Road, Suite A
Price, UT 84501
435-613-3716
TonyWright@utah.gov

Peter Youngbaer
Northeastern Cave Conservancy
National Speleological Society
3606 East Hill Road
Plainfield, VT 05667
802-272-3802
wnsliasion@caves.org

Carol Zokaites
Virginia Department of Conservation and Recreation
540-382-5437
carol.zokaites@dcr.virginia.gov