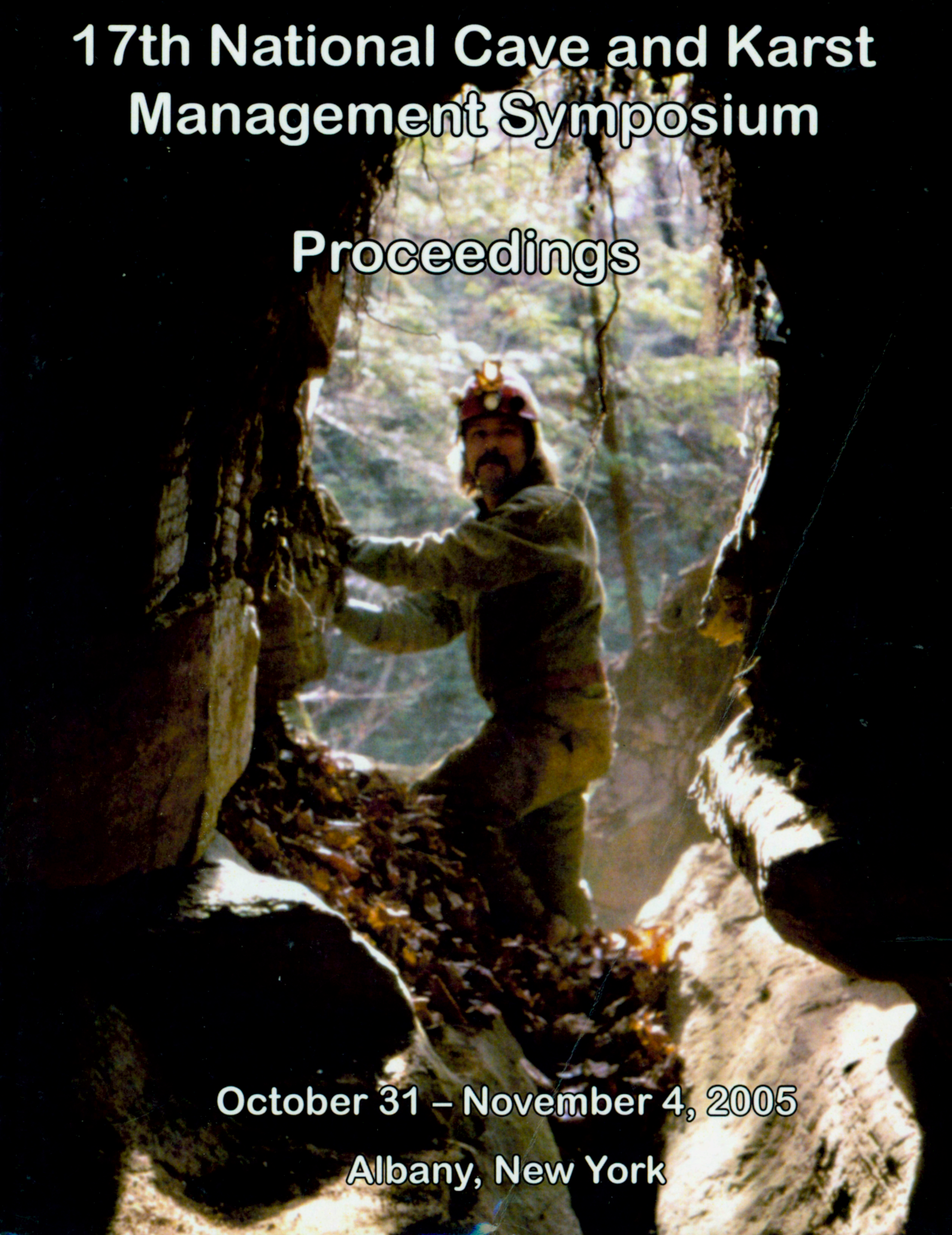
17th National Cave and Karst Management Symposium

Proceedings



October 31 – November 4, 2005

Albany, New York

Cover Photo by Joe Levinson: Paul Woodell taken in the Entrance to Jack Patricks Cave in Schoharie County, New York. It took first place as a color print in the 1997 print salon at the NSS National Convention in Sullivan Missouri. The camera was a Nikonous V with a 35mm lens using natural light on Professional Kodachrome 200

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Proceedings of the 2005 National Cave and Karst Management Symposium

Albany, New York
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Layout and Design by

GREYHOUND PRESS

Published by
The NCKMS Steering Committee
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Host Organization

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Brewery Ommegang
Girl Scouts Council of Central New York
Christa Hay of CT Mail

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WELCOME

I welcome you to Albany on behalf of your host, Northeastern Cave Conservancy, Inc.

Thirty years ago in Albuquerque, New Mexico, the first National Cave and Karst Management Symposium was convened. This year we mark that anniversary, reflect on the past 16 symposiums, and meet once again in the pursuit of improved management for caves and karst.

Bill Elliott, who is indexing proceedings of the NCKMS and related meetings, reports that since 1975 there have been 617 papers and 3015 pages. published in the NCMS and NCKMS Proceedings. This year we will add a considerable number of papers to that ongoing work.

Management, however, is about more than the amount of good information that is produced. It is also about understanding. Managers need to understand how studies can or should be used in management plans. Researchers need to understand how their work needs to be presented and reproduced. The NCKMS represent an opportunity for managers, scientists, and researchers to come together and discuss the important issues that both divide and combine their disciplines. This Symposium promises to be such a meeting. We hope you see this week as an opportunity for outreach, to the public and most critically to each other.

You will see many Northeastern Cave Conservancy members this week working as staff and in the audience around you. We are pleased to have everyone here, and expect all will take away new perspectives on the common issues faced by all karstlands managers and researchers.

Michael Warner
Chairman 17th NCKMS

MACRO-INVERTEBRATE SURVEY OF TIMPANOGOS CAVE

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Abstract

Under the funding of the National Park Service's Inventory and Monitoring Program, Dr Riley Nelson of Brigham Young University was contacted to perform a two-year survey to identify the macro-invertebrate species of the Timpanogos Cave. Species were collected in 87 pitfall traps placed throughout the entire cave system. These traps were collected every two weeks, sorted, and identified. Preliminary results show that a total of 29 taxon were collected, most from Sciaridae, Mycetophilidae, and Anobiidae. From this study, indicator species will be selected for monitoring the health of the cave.

CAVE RESOURCE INVENTORIES: WHY ARE THEY IMPORTANT?

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Abstract

Cave resources are defined as all of the secondary attributes and features, both natural and man-made, that reside within the confines of the cave or cave system. Natural features include the biota, paleontology, mineralogy, speleothems, and sediments. Man-made features can be of archeological, historic, or cultural origin. In order to effectively manage, protect, and conserve caves, cave systems, karst areas/ecosystems, and cave resources in general, it is important to have basic knowledge of the physical extent, nature, and attributes of the system/area/resource. Resource inventories along with geographic data and photo documentation provide the baseline of information necessary to understand cave and karst resources and ecosystems. Resource inventories can be conducted graphically or as a dedicated list. The Hoffman Institute uses both types of inventory data to generate resource inventory maps of general features, hydrologic features, and archeological/cultural features. Project areas where resources inventories have been conducted include Coldwater Cave, Iowa; caves of Isla de Mona in Puerto Rico; and caves in the south-central Kentucky area. Synthesis of this information into maps, databases, and Geographic Information Systems provides the framework from which to make sound and intelligent resource management decisions. Such baseline data and information is also a starting point for scientific research.

Introduction

In order to effectively manage, protect, and conserve caves, cave systems, karst areas/ecosystems, and cave resources in general, it is important to have basic knowledge of the physical extent, nature, and attributes of the system. Geographic data, resource inventories, and photodocumentation provide the baseline of information necessary to understand cave and karst resources and ecosystems. Synthesis of this information into maps, databases, and Geographic Information Systems provides the framework from which to make sound and intelligent resource management decisions. Such baseline data and information is also a starting point for scientific research.

Geographic Data

With respect to caves, cave systems, and karst areas in general, there are two basic types of geographic data: surface geographic data and cave survey data. Surface geographic data consists of the location and cataloging of physical features on the land surface. This includes locations of karst features (cave entrances, springs and spring seeps, swallets sinkholes, karst windows, sinking streams), surface water and drainages (lakes, ponds, rivers, and streams), surface rock outcrops, and any other features that are related to the caves and karst area.

Surface geographic information can be found on topographic maps, geologic maps, and aerial photographs. Reference to surface features can also be found in reports and written accounts about the area. However, in order to have the most complete data, it is necessary to do field reconnaissance to identify and locate features not shown on existing maps.

Once all of the surface geographic information is collected it should be cataloged and referenced to explicit location references (surface benchmarks, latitude and longitude, UTM coordinates) and plotted on a base map (which should include surface topography). The base map is the first layer of geographic information to which all other information layers will be referenced.

Geographic information also includes cave survey data which defines the horizontal and vertical extent of a cave or cave system. The way to obtain cave survey data is to actually map the cave. The objective of cave surveying is to collect distance, bearing, and vertical data that will later be made into a cave map.

Another important component of the survey data is passage dimensions. These data are recorded in terms of where the survey station lies with respect to the left and right walls and to the ceiling and floor of the cave passage.

The final component of the cave survey data is a detailed sketch, done to scale, of cave passages and features along the survey line. Because caves are three-dimensional entities, sketches need to be done in plan view, profile, and in cross section. Passage features and attributes are shown symbolically on the sketch. Features and attributes that should be noted on the sketch include: domes, skylights, pits, ledges, slopes, changes in ceiling height, composition of the material covering or making up the floor, speleothems, coatings, and water (flowing, ponded, sumped, and seeps). Other important things to note include wind (or changes in air movement), directions of water flow, passage terminations, biology, bones, and archeological/historic/cultural features.

More often than not, caves in an area of interest have not been mapped. In that case it will be necessary to instigate cave mapping work. Sometimes even if the caves have been mapped, the data or the maps may not be to modern survey standards. For some very old surveys, a map may exist but the data that produced it does not. In either case, re-survey is in order.

As cave survey data are collected, the distance, azimuth, vertical readings, and passage dimensions are input to a cave data reduction and plotting program. The data is converted to XYZ coordinates and plotted by the software. The result is a preliminary line plot showing the horizontal and vertical extent of the cave and its passages. Referencing the cave data to surface coordinates shows how the cave passages relate to surface features. Some reduction and plotting software can use the passage dimensions along with the XYZ coordinates to make volumetric plots of the cave passages. These programs also make it possible to rotate cave and volumetric plots in three dimensions. This is a valuable aid for envisioning the layout of a cave system and for detecting geologic and/or hydrologic patterns which are not obvious otherwise.

One of the primary reasons for collecting cave survey data is to produce cave maps (Figure 1). The cave plot, passage dimensions, and sketches are the necessary components of making a good map. The cartographer integrates these data into a map of the cave in plan and profile. Cross sections are added to the plan view making for a more complete three-dimensional representation of the cave. The availability of high powered PCs and easy-to-use drawing programs make computer cartography possible to a wider range of cave map makers. Today, most all cave cartography is done digitally.

A cave map, in any stage of completion, serves as an underground base map from which all future work can be referenced. An integrated cave map–surface map makes for a powerful tool for cave management and from which to conduct work for resource inventories, restoration, rescue planning,

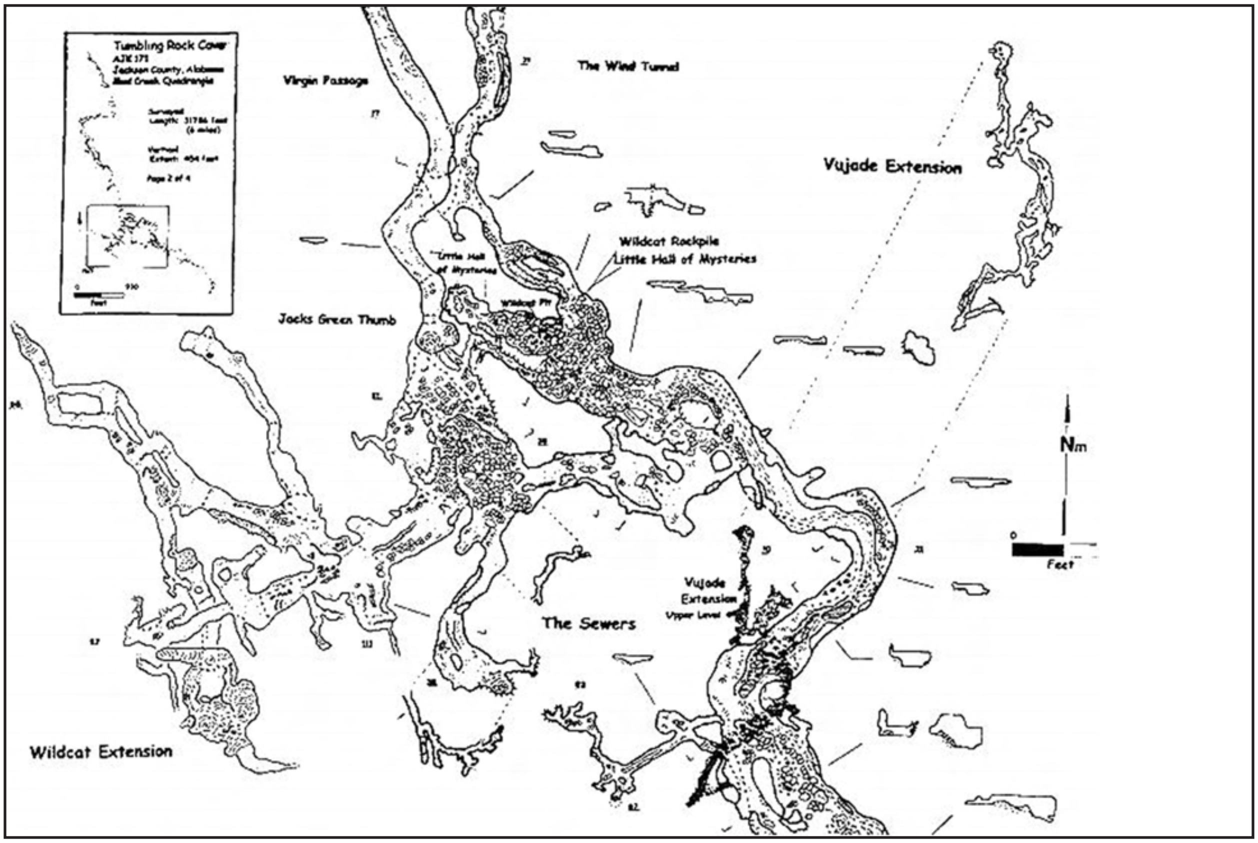


Figure 1. A portion of a map of Tumbling Rock Cave, Alabama,

impact surveys, and ultimately, research.

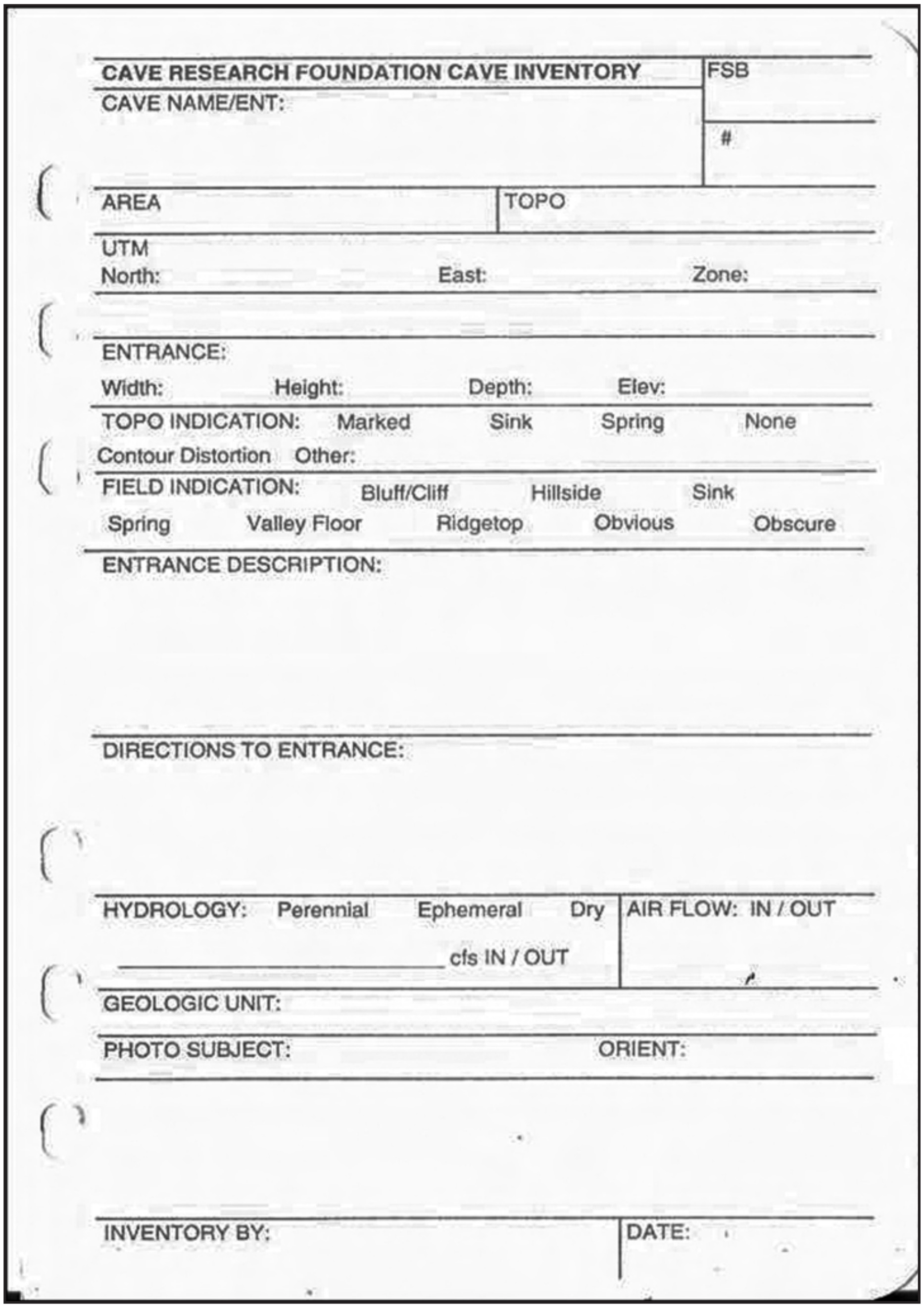
Cave Resource Inventories

Cave resources are defined as all of the secondary attributes and features, both natural and man-made, which reside within the confines of the cave or cave system. Natural features include the biota, paleontology, mineralogy, speleothems, and sediments. Man-made features can be of archeological, historic, or cultural origin.

The first step in managing, protecting, and studying caves resources is to know what and where they are. Resource inventories are descriptive lists of the cave resources referenced to survey stations. Most resource inventories are done in conjunction with the cave survey and collect only very basic information on the resources such as location or simple descriptions. Basic training and the use of field guides can supply enough expertise for data collectors to provide more descriptive surveys.

Resource inventories are generally done during the survey. Detailed sketches and notations from the survey notes can provide a generalized list of the cave resources. A resource inventory team can follow up on the generalized list and provide more detailed descriptions of the resources and the general cave conditions. Resource inventories can also be conducted as narrative descriptions or lists (Figure 2). Inventories can also be done on pre-printed checklist sheets which show a list of possible resources (Figure 3). The person inventorying simply checks the list. In either case, the data should always be referenced to survey stations.

Once the general inventories are done, it falls to the specialist with expertise and training in a particular field (biologists, paleontologists, or archeologists) to conduct detailed inventories and identifications. As resource inventory data is collected, the descriptive information needs to be entered into a database. Data in this format can then be searched and queried quickly and efficiently. Some cave data reduction and plotting programs have database functions that allow resource information tied to survey stations to be entered into a database. Plots or screen views can be produced which show the resource data displayed next to the survey station. Dedicated GIS programs are ideal



CAVE RESEARCH FOUNDATION CAVE INVENTORY | FSB | #

CAVE NAME/ENT:

AREA | TOPO

UTM
North: East: Zone:

ENTRANCE:
Width: Height: Depth: Elev:

TOPO INDICATION: Marked Sink Spring None
Contour Distortion Other:

FIELD INDICATION: Bluff/Cliff Hillside Sink
Spring Valley Floor Ridgetop Obvious Obscure

ENTRANCE DESCRIPTION:

DIRECTIONS TO ENTRANCE:

HYDROLOGY: Perennial Ephemeral Dry | AIR FLOW: IN / OUT
______________ cfs IN / OUT

GEOLOGIC UNIT:

PHOTO SUBJECT: ORIENT:

INVENTORY BY: | DATE:

Figure 2. Cave inventory form.

for combining cave plots and maps with attribute tables that contain inventory data.

Photo documentation

Photo documentation is an often overlooked but extremely important component of baseline data, especially if photographs are referenced to survey stations. A picture is indeed worth a thousand words, so photography serves as a superior component in resource inventories. A camera comes in extremely handy during surface reconnaissance in cataloging cave entrances (especially in areas where there are many cave entrances) and other karst features. In-cave photography provides excellent visual information on the nature, size, shape, and contents of cave passages and also serves to document the data collection process or new discoveries.

Photography is integral to photo monitoring programs in caves. For these programs, areas of the cave are photographed to document the condition of the passages and features at a point in time. The sites are visited on a regular basis and re-photographed. The pictures can then be compared to determine areas that are being degraded over time.

Good photographic records augment all of the geographic baseline data. A photographic archive is an important component for good interpretive and educational programs.

As with resource inventory data, scanned photographs or digital images can also be catalogued, archived into a database, and referenced to surface or underground locations.

Integrating the Baseline Data

In order for baseline data to be used efficiently

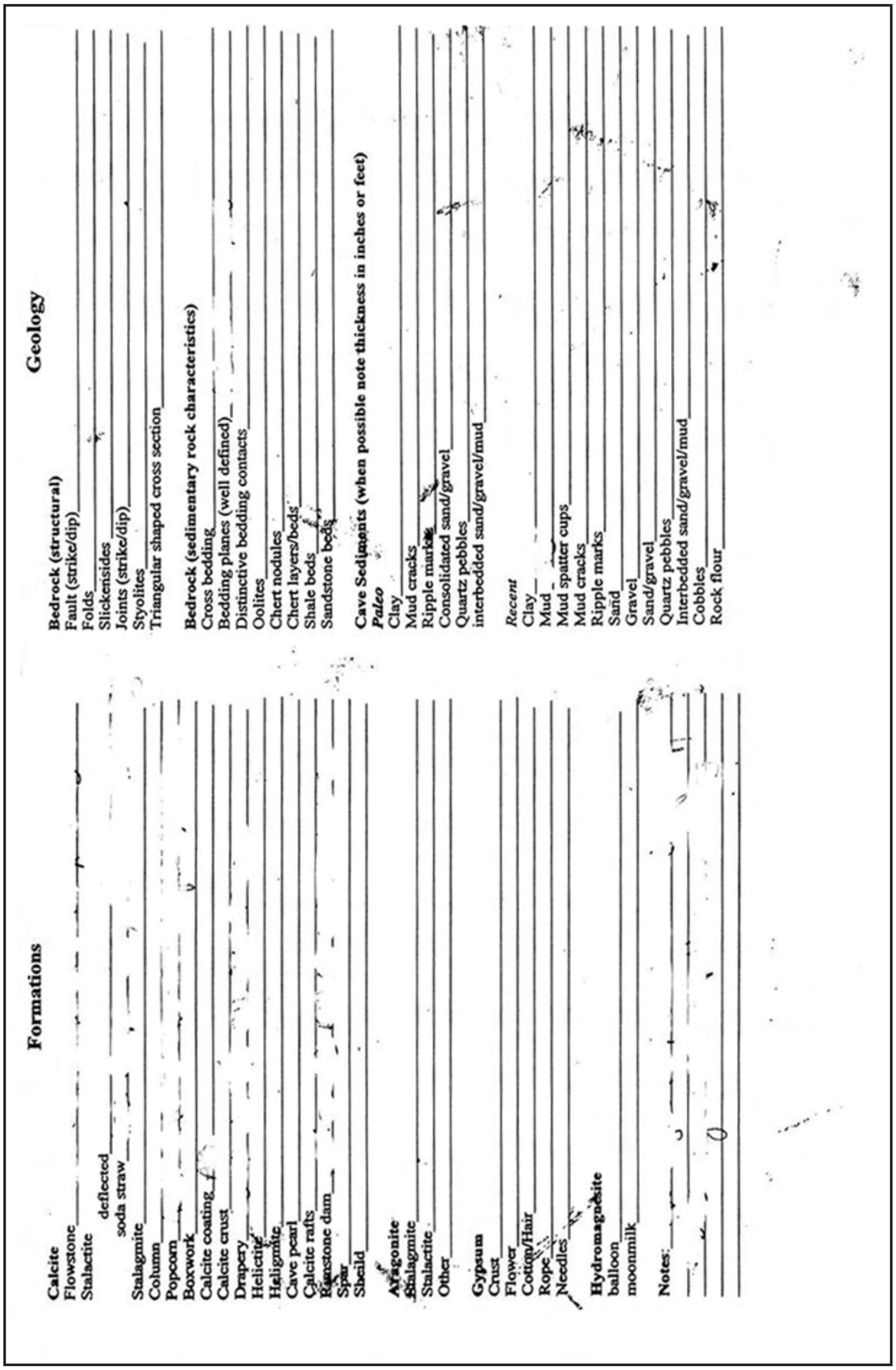


Figure 3. Inventory check list sheet

and effectively, it should be integrated in a way that combines basic map information, database information, and the photographic catalog into a graphic, interrelational format that is basically a Geographical Information System (GIS). A GIS integrates database capabilities with the visual perspective of a map.

The advantage of a GIS is its ability to produce graphics on the screen or on paper and the ability for that data to be searched, queried, and ultimately analyzed. This capability makes for an important tool not only in cave and karst management but also in research and outreach.

Case Studies

The Hoffman Environmental Research Institute has used resource inventories in several diverse cases. Resource inventory information was extracted from survey notes for Coldwater Cave, Iowa, and Isla de Mona, Puerto Rico, and resource inventories were conducted for Munin and Garnett Caves in south central Kentucky. This information was compiled into different databases and presented to resource managers and shareholders in order to allow them to make informed decisions concerning their karst resources. The Compass database function was used for Coldwater Cave, and the ArcGIS attribute tables were used for the caves of Isla de Mona, Munin Cave, and Garnett Cave. These databases were used for research projects, outreach, and education.

The Hoffman Institute has been working to glean information from the cave surveys of Coldwater Cave in Winneshiek County, Iowa, to be used for a hydrologic feature inventory. The survey notes were searched for all references to dome locations and underground drainage divides, and once found, these locations were entered into an Excel spreadsheet and then imported into Compass' database function. Underground drainage divides and domes were integrated into a line plot. The line plot illustrated where water was entering Coldwater Cave by showing its many insurgence points (Figure 4). In this particular case, the inventory and database was useful not only in terms of research but also in terms of local land use. This information was used in karst hydrogeology studies of the Coldwater drainage basin, and was also used in educational presentations made to local residents and landowners.

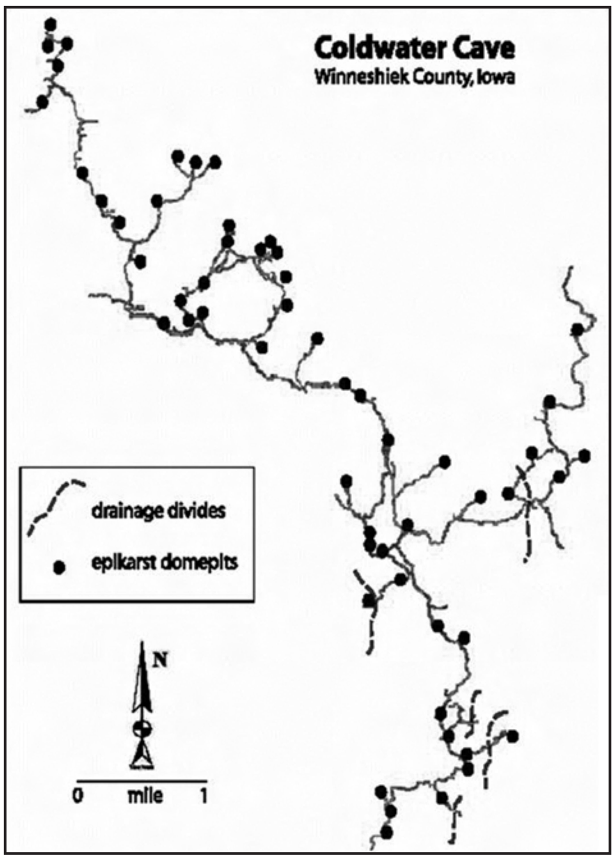


Figure 4. Line plot illustrating insurgence points.

The second case study involves the island of Isla de Mona, Puerto Rico. Isla de Mona is a natural reserve open to research and recreation. The Puerto Rico Department of Natural Resources issues public camping permits and hunting permits. The public often camps on the island during hunting season and the caves are open to these people if they can find them. Some cave entrances had paths leading to them with signs at the entrance. Many of these caves are located near major camping areas.

The Hoffman Institute in cooperation with the Isla de Mona Project and the Puerto Rico Deptment of Natural Resources is involved in an ongoing project to map and inventory the flank margin caves on Isla de Mona. Thorough surveys are conducted with detailed sketches and notations especially incorporating any historic artifacts or pictographs discovered (Figure 5). Because the caves are not closed to the public, these historic and cultural resources are highly susceptible to impact. Photographs were taken along with the survey to help document these artifacts and pictographs. The surveys and photographs are compiled into a database for resource managers in Puerto Rico.

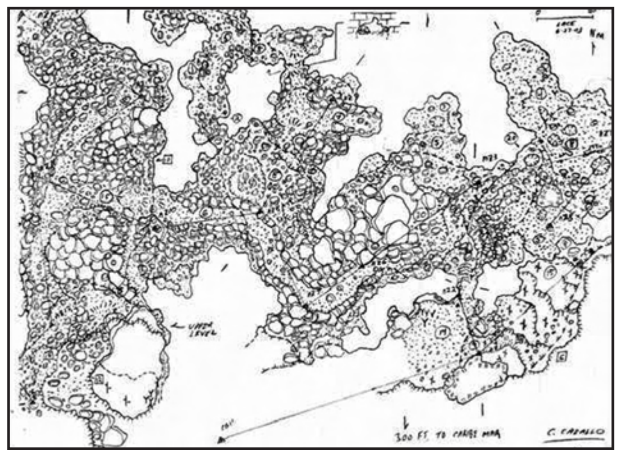


Figure 5. Sample detailed sketch.

The inventories gave resource managers a tool through which they could evaluate the usage and accessibility of caves on Isla de Mona. In order to help protect these valuable resources, the mowing of trails to caves was stopped and entrance signs were removed. Camping areas were changed to increase distance between campers and caves. Ideas for the future include creating an interpretive display to educate the public in the main cave near the main camping area.

In 2005 The Nature Conservancy invited the Hoffman Institute to map and inventory Munin and Garnett Caves located in Hart County, Kentucky. The Nature Conservancy wanted to have an inventory of what biological, historical, and hydrological resources were in their caves. The caves were mapped through detailed surveys and a checklist

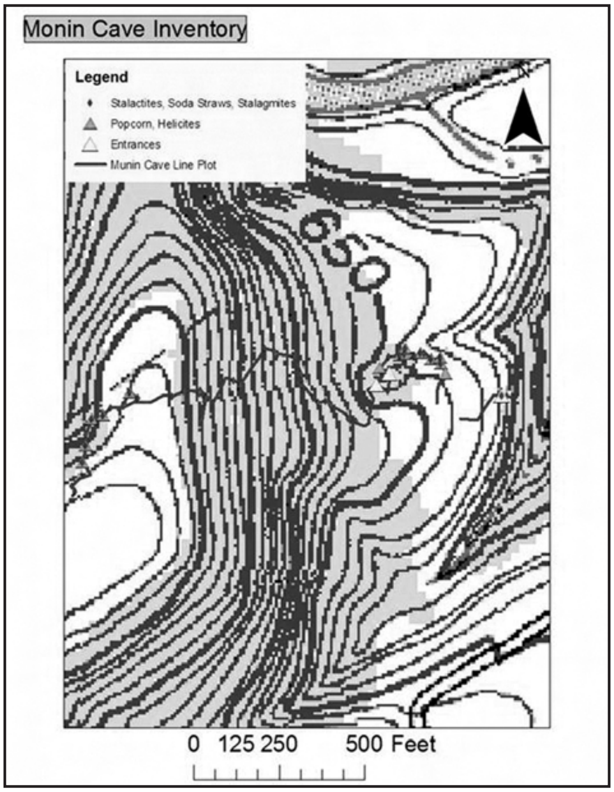


Figure 6. Final GIS layer.

inventory was used to denote important formations, historical signatures, and biological components. Photo documentation was conducted and referenced to survey stations to display each of these aspects. Finally, all this information was compiled into a GIS layer (Figure 6). The map and GIS layers representing the different inventories allowed The Nature Conservancy to develop a monitoring program and to acquire additional land if necessary to protect their resources.

Conclusion

Resource Inventories are important to resource managers because they allow for better protection of caves and karst. Monitoring programs can be developed to ensure better understanding and protection of these resources into the future. Increased knowledge of cave and karst resources allows for increased education and outreach to stakeholders and the general public. Finally, resource inventory databases will provide the baseline data for future scientific research. Ultimately it is research that will further the knowledge and understanding about cave and karst systems, resources and ecosystems.

Acknowledgements

The authors would like to acknowledge The Coldwater Cave Project, The Puerto Rico Department of Natural Resources, The Isla de Mona Project, and The Nature Conservancy.

CAVE FAUNAL STUDY FOR THE INTERSTATE 66 E.I.S (SOMERSET TO LONDON, KENTUCKY)

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Abstract

A detailed cave faunal investigation was performed within the scope of a larger karst and geohazards study on the proposed corridor for Interstate 66 in Pulaski and Laurel Counties, Kentucky. The assessment included the five basic steps generally required in National Environmental Policy Act (NEPA) technical studies. A total of 63 caves were visited revealing the presence of 114 taxa. Of the sites sampled, 29 of them were inhabited by globally rare species. The presence of 28 species of troglobites and stygobites was documented in the large cave system associated with Sinking Valley. This is the second largest assemblage of obligate subterranean species known in North America, second only to the Mammoth Cave System. A vulnerability rating using GIS mapping for karst areas within the study bands was developed: (1) low — no known caves or fauna; (2) moderate — cave present; (3) high — cave present with known fauna; (4) very high — cave present with globally rare species. In addition a cave cricket foraging area was buffered around all cave entrances and known or inferred passages.

Introduction

The purpose of the cave faunal inventory was to be encompassed within the inventory of karst features (Figure 1) and geohazards found within the Interstate 66 (Somerset to London, Kentucky) study bands identified by the I-66 Citizens Committee. The firm of Gannett Fleming Engineers and Architects, P.C. was employed to prepare the Karst and Geohazards Study in conjunction with HMB Professional Engineers, Inc. Lewis and Associates LLC were hired as a sub-consultant to Gannett Fleming to prepare the karst faunal investigation.

Gannett Fleming implemented a three-phase approach to provide impact information in the areas of geologic resources and geohazards, hydrogeology, and karst fauna. The assessment included the five basic steps that are generally required in National Environmental Policy Act (NEPA) technical studies for Environmental Impact Statements (EIS): (1) data gathering and literature reviews, (2) field reconnaissance, (3) preparation of a report of existing conditions, (4) development of impact characterization and alternative comparison, and (5) a summary of opportunities for avoidance, minimization and mitigation of potential impacts.

Initially ten alternate bands were designated as possible routes for this interstate. Three preferred alternates were subsequently designated: (1) Kentucky 80 band (Figure 2), following the extant highway; (2) north band (band B), that extends roughly parallel and predominantly north of highway 80, and (3) south band (band D), that runs south of highway 80. The karst feature field inventory was performed prior to the initiation of the karst faunal study, analyzing the three preferred alternates in the western part of the project area where they are largely underlain by carbonate rock strata. A total of 1,129 karst features were identi-

Figure 1. The Short Creek karst window, a major karst feature of the I66 project area, created by collapse of the main stream passage of the Sinking Valley Cave System.

fied within the three bands, with virtually all karst features located in Pulaski County (to the east in Laurel County where the bands extend, non-carbonate strata do not occur at or near the surface). Forty-nine percent of the karst features inventoried were found within the KY-80 band, with 28% and 23% in bands D and B, respectively. Other environmental considerations (for example, coal and industrial mineral resources) were identified in bands crossing Laurel County.

Figure 2. Kentucky Highway 80 crosses over the Sinking Valley Cave System just south of the collapse feature known as Quarry Sink.

Previous bioinventory in caves of the I-66 project area

There has been no previous comprehensive survey of the cave fauna specific to the proposed Interstate 66 project area. Barr (1979) prepared a report for the Kentucky Nature Preserves Commission on the caves and cave fauna of eastern Kentucky. That report included Stab Cave in the project area and Baker Cave, which lies outside of the project area, but is part of the Sinking Valley Cave System that traverses under Kentucky Highway 80. Other caves in the vicinity that were sampled by Barr were Richardson Cave and Richardson Pit (2.5 miles east of Somerset) and Wind Cave (1.1 miles south of Ruth). These caves are far removed from the I-66 project area.

Barr (1979) reported three species from Stab Cave. These were: (1) the cave ground beetle *Darlingtonea kentuckensis*, reported as being a widely distributed species for which 59 caves were listed in seven Kentucky counties; (2) cave sheet-web spider *Porrhomma cavernicolum*, reported from a total of three caves in eastern Kentucky, characterized as having highly disjunct colonies within a wide range; and (3) the cave cricket *Hadenoecus cumberlandicus*, for which over 100 caves were listed from a 13 county area.

Baker Cave is a window into the upstream part of the Sinking Valley Cave System. Barr (1979) reported the following species from this cave: the cave ground beetles *Darlingtonea kentuckensis*, *Ameroduvalius jeanneli*, *Nelsonites jonesi*, cave crayfish *Orconectes australis packardi* (from Hobbs & Barr 1970), cave isopod *Caecidotea* sp., gammarid amphipods, cave cricket *Hadenoecus cumberlandicus* (from Hubbell & Norton 1978), cave salamander *Eurycea* larvae, plecopteran larvae, fish *Notropis* sp., *Schilbeodes* sp., chironomid fly larvae, dipluran *Plusiocampa* sp., springtail *Pseudosinella hirsuta*, millipeds *Pseudotremia* sp. and *Scoterpes* sp., and eastern pipistrelle bat *Pip-*

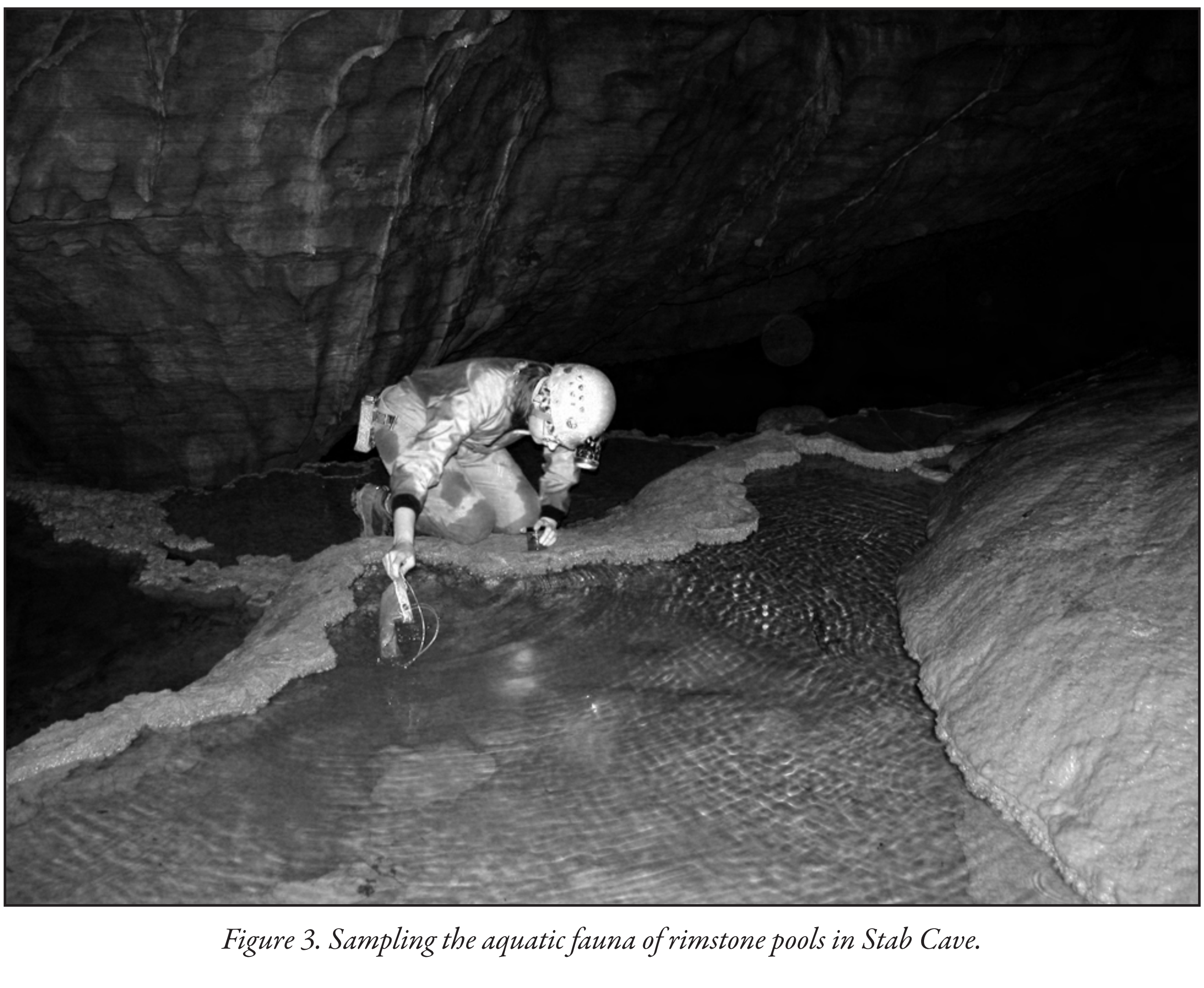

Figure 3. Sampling the aquatic fauna of rimstone pools in Stab Cave.

istrellus.

Thus, Barr (1979) demonstrated two species of obligate cavernicoles from the project area and eight more that probably occurred there as evidenced by their presence in the Sinking Valley Cave System.

In the broader view, the cave fauna of the project area lies within what has been termed the Rockcastle Fauna, a subset of the assemblage of animals that occur in the karst area associated with the edge of the Cumberland Plateau. Within the Rockcastle Fauna, two areas were delineated with slightly different faunas maintained by extrinsic barriers: (1) northern Rockcastle Fauna, in Rockcastle County and Pulaski County north of the Cumberland River (including the project area), and (2) southern Rockcastle Fauna, in Pulaski and McCreary Counties south of the Cumberland River. The fauna of these areas has been delineated by Barr (1967, 1979) and Lewis (1999).

Results: Cave and groundwater sampling for the I-66 EIS

For the karst faunal section of the Environmental Impact Statement a total of 63 sites, primarily caves (also springs, wells, and other windows into groundwater), were visited for the purpose of sampling the subterranean fauna. Besides hand sampling, pitfall traps baited with limburger cheese were placed in most of the caves visited. Leaf litter was sampled with Berlese extraction. Aquatic sampling (Figure 3) included plankton drift collections, plankton netting of rimstone pools, dipping water from shallow drip pools and running the water through a plankton net, and Karaman-Chappuis extraction of stream gravel habitats.

This bioinventory revealed the presence of 114 taxa. This was a diverse assemblage divided among 4 phyla, 11 classes, 27 orders, 55 families and 90 genera. Of the sites sampled 29 were inhabited by species classified as globally rare by the ranking system typically employed by natural heritage biologists (Table 1). Thirty-seven species were assigned global ranks (Table 1) of significant rarity: G1-13, G2-11, G3-and 13.

Of the fauna found in the project area, the terrestrial snail *Helicodiscus punctatellus* and millipede *Chaetaspis fragilis* were formerly only known associated with the Mammoth Cave System in central Kentucky. One taxon, the stygobitic copepod crustacean *Itocyclops* undescribed species, remains known only from Stab Cave and is thus as presently understood endemic to the I-66 corridor. Another millipede *Pseudotremia* undescribed species is apparently endemic to the Sinking Valley Cave System, but occurs in caves outside of the road bands. The troglobitic carabid beetle *Pseudanophthalmus* undescribed species is also known from a cave west of the study area. Significant vertebrates noted in the caves of the I-66 project area were the federal endangered gray bat *Myotis grisescens* and Rafinesque's big-eared bat *Corynorhinus rafinesquii*.

The presence of 28 species of troglobites and stygobites was documented in the large cave system associated with Sinking Valley (Table 2). This is the second largest assemblage of obligate subterranean species known in North America, second only to the Mammoth Cave System (Mammoth Cave National Park). Of the preferred bands, both the Kentucky 80 and north band alternatives cross this cave system. The southern band avoids Sinking Valley, but has a planned interchange in the sinking stream that flows into Cedar Creek Cave. Fourteen species of obligate subterranean invertebrates were found in this cave. Similarly, 15 obligate subterranean species were found in Stykes Cave that occurs

Table 1. Simplified criteria for global rarity rankings (G-ranks).

Global Rank	Number of global occurrences	Characterization
G1	1-5	critically imperiled
G2	6-20	imperiled
G3	21-99	vulnerable
G4	>100	apparently stable
G5		stable

Table 2. Obligate subterranean species associated with the Sinking Valley Cave System, Pulaski County, Kentucky.

Scientific Name	Common Name
Sphalloplana percoeca	cave flatworm
Carychium stygium	terrestrial snail
Helicodiscus punctatellus	terrestrial snail
Itocyclops undescribed sp.	groundwater copepod
Pseudocandona jeanneli	Jeannel's groundwater ostracod
Pseudocandona undescribed sp.	groundwater ostracod
Caecidotea stygia	cave isopod
Miktoniscus barri	cave terrestrial isopod
Crangonyx castellanum	cave amphipod
Orconectes australis	cave crayfish
Phanetta subterranea	Subterranean sheet-web spider
Porrhomma cavernicola	Cavernicolous sheet-web spider
Anthrobia mammouthia	Mammoth cave sheet-web spider
Hesperochernes mirabilis	cave pseudoscorpion
Pseudotremia undescribed sp.	Sinking Valley cave milliped
Scoterpes copei	Cope's cave milliped
Chaetaspis fragilis	Fragile cave milliped
Pseudosinella christianseni	Christiansen's cave springtail
Pseudosinela hirsuta	Hirsute cave springtail
Sinella barri	Barr's cave springtail
Sinella hoffmani	Hoffman's cave springtail
Sinella krekeleri	Krekeler's cave springtail
Litocampa undescribed sp.	cave dipluran
Ameroduvalius jeanneli	cave beetle
Darlingtonea kentuckensis	cave beetle
Nelsonites jonesi	cave beetle
Pseudanophthalmus undescribed sp.	cave beetle
Spelobia tenebrarum	cave dung fly

in the valley to the south of the southern band.

GIS mapping employed a cave vulnerability rating within the study bands: (1) low — no known caves or subterranean fauna; (2) moderate — cave present; (3) high — cave present with known fauna; (4) very high — cave present with globally rare species. In addition an area was suggested to protect cave cricket foraging grounds in a 500-foot diameter around all cave entrances and known or inferred passages.

Any site with globally rare species (G1, G2, or G3) was of particular significance. An index was developed that places an emphasis on sites where assemblages of two or more rare species occur, which was termed the composite rarity. In this index of composite rarity, a G1 species = 10 points, G2 = 5 points, and G3 = 3 points. To find the composite rarity index for a given site, a formula was employed:

$$A\ (\Sigma G1s) + B\ (\Sigma G2s) + C\ (\Sigma G3s)$$

An example of composite rarities for several caves in the I-66 corridor is presented in Table 3.

Conclusion

All band alternatives potentially affect significant cave faunal assemblages. The Kentucky 80 and northern bands cross the Sinking Valley Cave System. While the southern band avoids this major system and its fauna, it is on or near other smaller caves with significant fauna. The Kentucky 80 band has the merit of utilizing an extant road, whereas the northern and southern bands would entail construction across mostly new terrain. Many things, including the karst and its fauna, must be considered in such an undertaking and the final decision remains to be determined by the Kentucky Transportation Cabinet.

Table 3. Examples of composite rarity ranking of sites in the I-66 project area.

	Composite Rarity	Obligate Subterranean	Band Association
Stab Cave	91	19	Kentucky 80
Stykes Cave	79	15	Southern
Odell's Pit	79	14	Northern
Cedar Creek Cave	57	12	Southern
Cedar Creek Spring Cave	43	10	Southern
Cave #16	42	11	Southern
Blackhawk Cave	37	11	Kentucky 80
Blowing Cave	36	9	Between Ky 80 & Southern
Price Cave	33	8	Kentucky 80

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HAWAIIAN CAVE BIOLOGY: STATUS OF CONSERVATION AND MANAGEMENT

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Abstract

Caves on the main Hawaiian Islands support diverse communities of obligate cave-adapted species. First discovered in 1971, currently over 75 species of troglobites are recognized, including planthoppers, crickets, moths, beetles, spiders, pseudoscorpions, millipedes, centipedes, isopods, and others, with new species still being discovered. Efforts to protect these species began soon after their discovery, and are on-going. Systematics research using morphology, behavior, and molecular techniques is revealing much greater diversity among cave populations than assumed. Within some groups, each cave supports one or more distinct populations or species differing from neighboring cave populations in form, behavior, and DNA. Roots provide important food base for the ecosystem, and identification of plant roots in caves and management of the surface environment are essential for habitat protection. Management of the surface includes restoration of native vegetation where needed and removal of invasive alien plants, ungulates, and other harmful introduced species. Control of threats includes prevention of pollution by garbage, sewage, and chemical contamination. The Hawai`i State Cave Protection Law was developed to extend these protections to all caves statewide. Many significant caves occur in protected areas including national parks, national wildlife reserves, military reserves, Hawaii Natural Area Reserves, Nature Conservancy reserves, and other private protected land. Cave resource inventories and development of management plans with the necessary monitoring is on-going in many of these protected areas. Finally, two cave species facing imminent threat of extinction have been listed as endangered species, with delineation of critical habitats, and establishment of protected areas. Currently, the Cave Conservancy of Hawai`i and expansion of private, state, and federal protected lands are extending protection of Hawai`i's unique cave species.

Contribution No. 2006-005 to the Hawai`i Biological Survey

What cave species occur in Hawai`i, and where are they found?

Since the discovery of cave adapted invertebrates in Hawai`i Volcanoes National Park by Howarth in 1971, over 75 species of troglobites have been discovered on all the main Hawaiian islands. Counter to standard theories of cave species evolution, the youngest islands in the chain have the greatest number of species. Over 44 species occur on Hawai`i Island, the youngest at less than one million years old. Maui, at one to two million years old, has 19 species. Moloka`i, one to two million

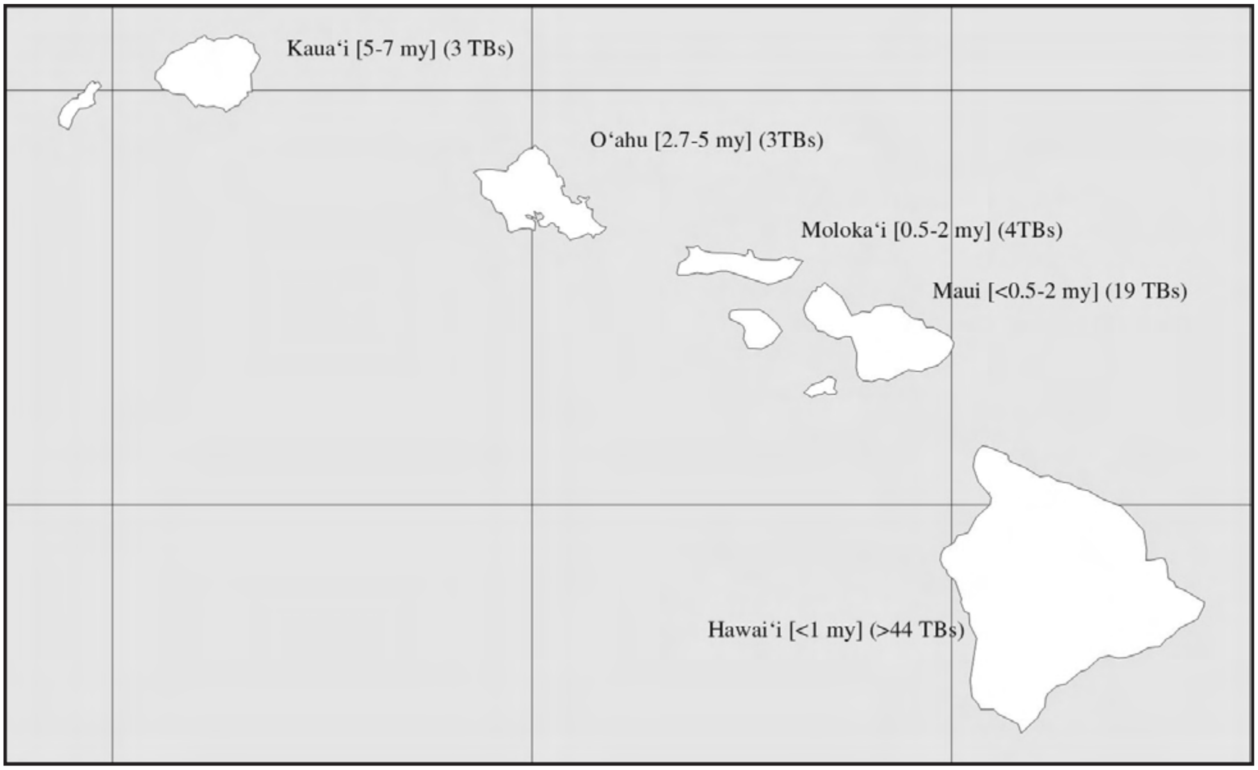

Figure 1. Map of main Hawaiian Islands with ages of major island building lava flows in brackets and numbers of terrestrial troglobites in parentheses.

years has four species, O`ahu, three to five million, and Kaua`i, five to seven million, have three species each. (Figure 1 and Table 1)

New cave species are still being discovered, and many cave species remain to be described. Furthermore, recent taxonomic studies using DNA, morphology, and behavior have shown that even those described in the past may include more than one species (Otte, 1994; Hoch and Howarth, 1993). Therefore, the number of species will continue to rise. In this paper, we will treat only the terrestrial species, but Hawai`i also has cave adapted aquatic species, mostly crustaceans, living in flooded interstices in lava and limestone near the coast. In the future additional marine, anchialine, and fresh water aquatic cave species will no doubt be discovered. Conservation and management of these coastal subterranean habitats raise similar issues as the terrestrial realm, but there are some unique concerns (Brock and Kam, 1997).

Like troglobites elsewhere, Hawaiian cave species live in an environment characterized by having calm air saturated with water vapor. This environment usually occurs only in deeper cave passages and intermediate-sized voids (mesocaverns) in cavernous rock deposits. The degree of cave adaptation and the diversity of species present are correlated better with the size of suitable habitat rather than age of the cave as had been assumed (Howarth, 1993; Hoch and Howarth, 1999). Hawai`i Island with its recent lava flows provides a vast subterranean system for cave life. Maui Island is intermediate in age and still has extensive areas of young lava. The older islands contain only relict caves, and few species persist. Most caves in Hawai`i are lava tubes (Peterson and others, 1994), but a few limestone caves occur on O`ahu, where there are raised coral reefs, and on Kaua`i in cemented coral sand dunes.

Why are cave-adapted species important?

Since the early 1970s, there has been a revolution in cave biology following the rediscovery of the lava tube fauna in Japan; the discovery of lava cave faunas in Hawai`i, Galapagos, Canary Islands, North America, and elsewhere; and the discovery of similar faunas in fractured rock terrains of diverse types, and of course in the tropics (Ueno, 1971; Howarth, 1983a; Juberthie, 1983). These faunas provide systems to independently test the evolutionary theories developed from the pioneering historic biospeleological studies done in temperate limestone caves (for example: Barr, 1968; Culver, 1982).

The Hawaiian Islands are an evolutionary laboratory ideally suited for study of troglobite evolution. (1) Cave species have evolved in a tropical, volcanic, oceanic island chain for which the ages of the islands are known. Evolution has occurred independently on each island (once cave adapted, cave species cannot survive on the surface, and movement between islands is impossible). (2) Closely related surface species are often extant in neighboring habitats, allowing comparison of epigean and cave adapted sibling species. (3) Lava flows reach from mountain ridges to the sea, and new lava flows and lava tubes continually form, allowing comparison of species at different elevations and in various lava tube ages. That is, troglobites occur in lava tubes from 2,400 meters elevation to the sea and from less than a year old to greater than 2 million years old. (4) Volcanoes of different ages and sizes occur on Hawai`i Island. The islands formed in sequence over the moving Pacific Plate, and are successively older to the northwest (Decker and others, 1987), allowing comparison of evolutionary processes among the islands. At least 12 taxonomic groups have independently adapted to cave life on more than one island, indicating that cave adaptation is a general process analogous to the adaptive shifts displayed by epigean species in the islands (Hoch and Howarth, 1999; Howarth and Hoch, 2005).

Howarth developed a bioclimatic model to explain the occurrence and evolution of cave species (Howarth, 1980). Five zones can be characterized by their abiotic and biotic environments: Entrance, Twilight, Transition, Deep Cave, and Stagnant Air Zones (Howarth, 1993). The extent of each zone is governed by the location, size, and shape of the entrances and passages; however, the boundaries between the zones are dynamic. The deep cave and stagnant air zones are usually found only deep within caves or beyond a passage constriction such as an n- or u-shaped deadend passage, which trap water vapor and carbon dioxide. Only a few caves extend into the stagnant air zone, but it is hypothesized that this is the environment characteristic of the mesocaverns (Howarth and Stone 1990). In both limestone and lava caves, obligate cave species are almost universally restricted to the two deeper zones, where the air remains saturated with water vapor. Many are found only in deadend passages beyond tortuous crawlways. The mesocaverns provide a large habitat for troglobite survival and dispersal.

Threats to cave species

Threats to cave species occur both on the surface and below the surface in the caves and mesocaverns. Surface alterations are caused by loss of native vegetation through land clearing, fires, and lava flows, introduced ungulates (feral pigs, goats, sheep, cattle) and other animals, alien invasive plants and diseases, mineral mining and quarrying, and other land use changes. Surface modification can also affect water resources in caves (for example: changes in drainage, impoundments, and stream channel changes). Subsurface alterations are caused by removal of entire caves, opening entrances, and alteration of cave entrances and passages that change the cave microclimate. Surface and underground pollution from human and animal waste, fertilizer, and pesticides can affect cave animals. Introduced species (rats, cane toads, cockroaches, millipedes) have invaded caves and prey on or compete with native species. People entering caves can disrupt the ecosystem by introducing toxins (for example, smoke) and other foreign materials, modifying passages to gain access thereby changing airflow, and damaging tree roots and other food resources Howarth, 1983b).

What is being done?

The problems of conserving Hawaiian cave adapted species were recognized from the time of their discovery in 1971 (Howarth, 1972; 1983b; Howarth and Stone, 1982). In 1978, Howarth initiated a proposal to protect two cave animals on Kaua`i, the no-eyed, big-eyed wolf spider (*Adelocosa anops*) and the terrestrial amphipod (*Spelaeorchestia koloana*) under the United States Endangered Species Act. The two species were formally listed in 2000. Stone presented a resolution supporting conservation of Hawaiian caves to the National Speleological Society Board of Governors in 1982, and this was followed by the establishment of the Hawai`i Cave Conservation Task Force (Howarth and Stone, 1982). Existing federal and state legislation protects native Hawaiian burials. Recently, a task force composed of native Hawaiians, cave owners, and cave scientists working with the Office of Historic Affairs under the Department of Land

and Natural Resources jointly developed a draft Hawai`i Cave Protection Act, which was passed by the state legislature after they strengthened the land owner section to require a written permission before cavers could enter caves.

Ideally, conservation of cave resources requires protection of the land overlying the caves through direct purchase by private conservancies or public agencies followed by elimination of introduced plant and animal species and restoration of the native vegetation. Cave management can then be based on the specific needs and threats to each cave, depending on the environment. For example on Kaua`i, limestone caves in fossil coral sand dunes were threatened by quarrying. The dune with the most important cave is now protected and quarrying was stopped. Non-native trees are being removed and native species (determined by a paleontological survey of the cave sediments) are being replanted. A few cave reserves have been established on private lands through conservation agreements.

Effective conservation programs are based on sound science developed through research. First, one needs to understand the systematics of the inhabitants; that is, how they are related to other animals. Systematics research determines whether a species is an alien invader or native, and if native, whether it is widely distributed in many caves or whether each population is distinct. Obviously, conservation actions should be based on such understanding. In fact, conservation biology programs can only be as good as the systematics upon which it is based. Clearly, conservation priorities differ according to whether troglobites are widespread in many caves across an island or separate species occupy each cave. The recognition that many Hawaiian cave adapted animals are restricted to a small area means that a variety of caves in as many areas as possible need to be protected to perpetuate the maximum level of biodiversity.

Research is also underway to develop effective management plans for protecting cave resources. A unique aspect of this research is to develop protocols to manage the surface environment to enhance the cave habitat below. The reason for this strategy is the fact that the main energy source for the ecosystem is plant roots that penetrate deep underground to obtain water and nutrients. In Hawaiian rainforests, the roots of native *`ohi`a lehua* trees (*Metrosideros polymorpha)* provide a major food source for cave species. A few other plant species are locally important, and a critical aspect for effective restoration is to identify plant roots in caves. In addition, monitoring protocols are being developed to determine long-term trends of sensitive cave populations.

Control of threats to caves and cave life that lie outside reserves is more difficult. These include prevention of garbage dumping and pollution of the caves and ground water by sewage and chemical contamination, and minimizing damage to caves from unrestricted entry by recreational cavers. These problems can be reduced through legislation and education. There is a dilemma posed with developing strategies for protecting cave resources: on one hand, one needs to make the resources known so that they will be less likely to be destroyed through ignorance during land use changes; however, publicizing the resources can lead to increased visitation and subsequent increased rate of destruction.

Howarth, Stone, and colleagues, working through B.P. Bishop Museum and within the auspices of the Hawai`i Cave Conservation Task Force have worked on cave inventories and management plans for a number of public and private land areas. These included military reservations on several islands, state Natural Area Reserves, National Parks, The Nature Conservancy of Hawai`i, and other private land. Following a detailed survey, a major cave on the island of Hawai`i was removed from the Agricultural Lots and re-zoned in conservation land. Cave inventories have also been conducted through the state and federal Environmental Assessment and Environmental Impact Statement processes, including an important biological and cultural cave threatened by geothermal development.

Additional cave surveys have been conducted by the Hawai`i Speleological Survey and the Hawai`i Grotto of the National Speleological Society. Recently the Hawai`i Cave Conservancy has purchased land containing a major cave on the island of Hawai`i.

Protection of land areas on the major Hawaiian Islands

Kaua`i is the oldest of the main Hawaiian Islands, and as already noted, has two endangered cave species. The U.S. Fish and Wildlife Service is developing a Recovery Plan for these species. Howarth has worked with private landowners to assist in establishment of three preserves protecting seven caves on 30 acres. Another cave entrance is being successfully protected as a "cave trap" in the middle of a golf course. The lithified coral sand dune at Mahualepu is being protected and native vegetation restored, as mentioned above.

On O`ahu several caves with cave species occur on military reserves, and Howarth has worked with the military to inventory the caves and make management recommendations. In one area, there are limestone caves in a raised coral reef.

Moloka`i and Maui have caves with cave species in the national parks, military reserves, state natural area reserves, and private land, including some owned or under lease by The Nature Conservancy. Surveys of the biology and paleontology have been conducted and management recommendations completed.

Hawai`i has the most caves and the longest lava tubes of any of the Hawaiian islands, and it also has the most cave species. These occur in national parks, national wildlife refuges, military reserve, state natural area reserves, state forest land, conservation zoned land, private land under control of the Cave Conservancy of Hawai`i, The Nature Conservancy, Kamehameha Schools, and numerous other land owners. Cave inventories, biological surveys, and management plans have been completed for Hawai`i Volcanoes National Park, Pohakuloa Military Training Area, Manuka Natural Area Reserve, and Kiholo Bay State Park among others.

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TABLE 1: NUMBERS OF TERRESTRIAL TROGLOBITES IN HAWAI`I

TAXA	HA	MA	MO	OA	KA
Crustacea: Amphipoda					
Talitridae (sandhoppers) *Spelaeorchestia*					1
Crustacea: Isopoda: Philosciidae (sowbugs)					
Hawaiioscia & Littorophilophiloscia	1	1	1	1	1
Arachnida: Acari (mites)					
Rhagidiidae: *Foveacheles*	1		1		
Arachnida: Araneae:					
Linyphiidae (sheetweb spiders) *Meioneta & Erigone*	>7	1			
Lycosidae (wolf spiders) *Lycosa & Adelocosa*	1				1
Oonopidae (six-eyed spiders) *Oonops*	1				
Theridiidae (cobweb spiders) *Theridion*	2	1			
Arachnida: Pseudoscorpionida: Chthoniidae					
Tyranochthonius		1		1	
Vulcanochthonius	3				
Myriapoda: Chilopoda					
Lithobiidae (rock centipedes) *Lithobius*	>1	1	1		
Myriapoda: Diplopoda					
Cambalidae (millipedes) *Nannolene*	>2	1			
Insecta: Collembola					
Hypogastruridae (springtails) *Neanura*	1				
Entomobryidae (springtails) *Sinella & Hawinella*	1	3		1	
Insecta: Orthoptera: Gryllidae (true crickets)					
Oecanthinae (tree crickets) *Thaumatogryllus*	2	2			
Nemobiinae (rock crickets) *Caconemobius*	>4	1			
Insecta: Dermaptera (earwigs)					
Carcinophoridae *Anisolabis*	1				
Insecta: Heteroptera					
Mesoveliidae (water treaders) *Cavaticovelia*	1				
Reduviidae (thread-legged bugs) *Nesidiolestes*	2				
Insecta: Homoptera: Cixiidae (planthoppers)					
Oliarus	>5	3	1		
Insecta: Coleoptera					
Carabidae (ground beetles) *Blackburnia & Tachys*	2	3			
Staphylinidae (rove beetles) *Nesomedon*	2				
Insecta: Lepidoptera					
Noctuidae (moths) *Schrankia*	>2	1			
Insecta: Diptera					
Phoridae (scuttle flies) *Megaselia*	2				
TOTALS	>44	19	4	3	3

MICROBIAL SPELEOLOGY: OPPORTUNITIES AND CHALLENGES

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Abstract

In caves, microorganisms (algae, bacteria, archaea, fungi, protoza, and viruses) are major producers and consumers of organic matter and contribute to the formation of several types of minerals. However, with the notable exception of sulfide-based ecosystems, little is known about community composition, their specific adaptations to the subterranean ecosystem, their biogeographical distribution or their ecology. Interdisciplinary studies, using recently developed techniques, are now providing the tools with which to make great strides in elucidating aspects of subterranean microbial ecology that go beyond the traditional "who's home" studies. As we come to realize the value of microorganisms in cave ecosystems, we are also realizing the impact that humans can have on these microbial communities. Advances in our understanding of the functioning of microorganisms in caves and of the means to protect and preserve them are critical to the health and beauty of caves and their ecosystems.

Introduction

Much remains to be learned about microbial communities in caves compared to what is known about vertebrate and invertebrate communities that inhabit caves. Several intriguing and fascinating areas of research concerning the nature of microorganisms that exist in caves include:

1. Are there indigenous species of microorganisms in caves that would exist in caves whether humans were ever present or not? Are there similarities among these indigenous microbial species from caves across the planet?
2. Much of the research on microorganisms in caves has been conducted using traditional culturing techniques. Research from other fields of microbiology, using molecular biology techniques, has shown that we are able to culture only a small fraction of what's out there in the environment. These techniques are now being applied to microbial communities in caves to greatly expand the ability of biotic surveys to detect the rich microbial life present in caves.
3. Recent research has revealed the presence of unique communities of microorganisms in lava tubes, iron and manganese deposits in caves, sulfur-dominated caves, and low-nutrient environments of caves. Further research into these

intriguing habitats promises to help fill in the branches of the tree of life.

4. Within these unusual microbial habitats in caves we're learning that microorganisms interact with the mineral surfaces, particularly in iron–manganese, sulfur, and moonmilk environments.
5. If life exists on other planets in our solar system and beyond, it will likely be found in the subsurface of these extraterrestrial environments because of harsh surface conditions. Caves serve as an excellent analog for extraterrestrial subsurface environments.
6. For primary school children, caves serve as a wonderful vehicle for learning earth and life sciences. New efforts are turning the results from scientific research into creative activities and content to engage students in learning science.

Associated with these great research opportunities into microbial communities in caves, are significant challenges in carrying out effective research. These include:

1. Most microbial research studies in caves center around the question of "Who's Home?" We must move beyond this question to questions centering on the roles that microorganisms play in the cave ecosystem and the interactions among microorganisms.
2. Culture-based biotic surveys remain important, but we must incorporate more culture-independent studies, making effective use of molecular methods. These must be integrated into culture-dependent studies that allow us to study the physiology of the newly discovered species that molecular methods reveal.
3. Discovering and creating new ways to fund this research are critical. These kinds of studies are expensive to carry out.
4. The number of microbial biospeleologists in the United States is extremely small compared to the work that needs to be done. Training the new generation of microbial speleologists is important.
5. To conduct microbial speleology studies effectively, we need to develop best practices, drawing upon mainstream microbiology and molecular biology, tempered by the constraints of working effectively with cave microorganisms.

Opportunities: Exploring the Existence of an Indigenous Microbial Community in Caves

Early studies of microorganisms in caves relied entirely on culture-based studies and tended to reveal microbial species that were closely related to organisms already known from surface studies. This is not surprising given that we haven't learned how to grow most microorganisms from most environments. With the advent of molecular biology techniques pioneered by Norm Pace, we can now study microorganisms through their genetic sequences and a huge amount of diversity is now being revealed from the microbial world. Studies of sulfur-dominated caves are revealing the presence of a diverse community of *Epsilonproteobacteria* (Engel *et al.* 2003), almost all of which is novel (that is the species of bacteria are new to science). Comparison of genetic sequences from studies by Engel and others (Engel *et al.* 2003, 2004a, Lower Kane Cave in Wyoming; Engel *et al.* 2001, Cesspool Cave in Virginia; Vlasceanu *et al.* 2000, Frassasi caves in Italy; and Moville Cave in Romania) to those of Northup *et al.* (2004; unpublished data, Cueva de las Sardinas in Tabasco, Mexico) reveal an amazingly close similarity among genetic sequences, hinting that at least among the *Epsilonproteobacteria*, an indigenous community may exist in sulfur springs and caves. These comparisons, done by Annette Summers Engel and Megan Porter begin to address the issue of whether there is an indigenous community in caves.

Preliminary studies by Northup *et al.* (unpublished data) of genetic sequences from actinomycete communities on walls of Four Windows Cave, a lava tube in El Malpais National Monument, New Mexico, demonstrate groupings of genetic sequences with Mammoth Cave bacterial genetic sequences. Among the sequences studied, one of the Four Windows sequences groups with a *Chloroflexi* sequence from Mammoth Cave and another groups with a *Betaproteobacteria* sequence, also from Mammoth Cave. In both these instances, there are no other close relatives, suggesting that these are novel organisms, most closely related to each other.

But these studies are like a jigsaw puzzle in which you've put in the first pieces in a final picture for which you have no image to guide you. We know so little about cave microbial communities that it is too early to know whether a true indigenous community of microorganisms exists in caves — just tantalizing hints!

Opportunities: Using Molecular Techniques to Study Microbial Communities and Discover Novel Organisms

As will be discussed below in culture-independent versus culture-dependent challenges section, there are strong advantages to using culture-independent, molecular techniques to study cave microbial communities. One of the very first studies of cave microorganisms to use molecular methods is that of Vlasceanu and colleagues (1997) who studied the microbial mat organisms in Movile Cave. Using these techniques, Summers-Engel and Porter (for example, Engel *et al.* 2003), Barton (for example, Barton, Taylor, and Pace 2004), Northup (for example, Northup *et al.* 2003; Spilde *et al.* 2005), and others have begun to study low nutrient and mineral-rich environments, revealing the diverse communities of microorganisms associated with caves. Chelius and Moore (2004) and Northup *et al.* (2003) discovered rich communities of mesophilic Archaea in Wind Cave and Lechuguilla Cave respectively. Up until mid-2005, no one had succeeded in growing any of the mesophilic Archaea, which were discovered for the first time in 1992 (DeLong 1992). To discover many archaeal genetic sequences in caves was a revelation. However, it's a revelation that will become commonplace as we increase our use of molecular biology techniques to study cave microbial communities. One thing that strikes you when you look at family trees of bacterial genetic sequences (that is phylogenetic trees) from caves and their nearest relatives is that many of the genetic sequences from caves have no really close relatives, especially among the known cultured bacteria. Many of the organisms whose sequences group with cave sequences are uncultured and represent novel biodiversity. Thus, culture-independent techniques provide us with the opportunity to discover many new microorganisms in caves.

Opportunities: Studying Microbe-Mineral Interactions in Caves

The international Breakthroughs in Karst Geomicrobiology and Redox Geochemistry meeting (Sasowsky and Palmer 1994) brought together scientists who study caves, microorganisms in caves, and interactions between microorganisms and rock substrates. This landmark conference heralded the beginning of a wealth of studies using cave ecosystems to study microbe-rock interactions. Northup and Lavoie (2001) reviewed these studies and described how microbes play both active and passive roles in the formation and weathering of the interior lithology of caves. The true significance and the exciting developments, however, lie in the combining of forces by geologists and biologists to effectively study how microbes influence geology and vice versa. For several decades we have suspected and begun to document that microorganisms play a role in dissolution and precipitation reactions in speleothems, especially those of a sulfur, manganese, iron, nitrogen, or carbonate nature.

Several studies highlight the involvement of microorganisms in oxidizing sulfides to sulfuric acid, which has been shown to be a powerful force in speleogenesis and cave enlargement (Barton and Luiszer 2005; Engel *et al.* 2004b; Hose *et al.* 2000). Several potential new species of sulfide-oxidizing bacteria in the *Epsilonproteobacteria* and the *Gammaproteobacteria* have been discovered in caves with strong inputs of hydrogen sulfide. The biodiversity associated with these environments is revealing many new species as detailed above and is likely to shed light on similar sulfur-dominated reactions in other environments.

Another forefront of activity centers around studies of iron and manganese-oxidizing bacteria and their ability to dissolve carbonate rocks in caves (Northup *et al.* 2003; Spilde *et al.* 2005). Extensive deposits of ferromanganese deposits in Spider and Lechuguilla Caves appear to form an underground soil on cave walls and ceilings, hence the name speleosols. Bacterial species present in these deposits can be cultured on site and we have demonstrated that these cultures can produce similar mineral morphologies in the laboratory. These reactions produce acidity, which can contribute to carbonate dissolution and the formation of the underlying punk rock. A wealth of novel biodiversity is being discovered in these deposits also.

These examples are just some of the fascinating new studies that explore the interactions of microorganisms and cave minerals. Many additional studies can be found in the special issue on "Cave Geomicrobiology" in the August 2001 issue of *Geomicrobiology Journal* and in subsequent issues of this journal and in *Journal of Cave and Karst Studies.*

Opportunities: Caves as Laboratories for Developing Life Detection Strategies for the Search for Extraterrestrial Life

Lava tubes and other caves are an important analogue for habitable environments on Mars. During the earliest history of Mars, a time during which biological processes may have been initiated, similar life could have been sustained in the vadose zone environments offered by short-term habitable zones. The unique environmental niche represented by life found underground in the vadose zone on the Earth, as represented by microbial life found around the world on the walls of caves, especially lava tubes, represents a superlative opportunity for studying easily accessible subsurface microbial communities and associated materials.

Are there biosignatures left by these extant and extinct microorganisms that can be used to detect life on Mars and elsewhere? Boston *et al.* (1992) and McKay *et al.* (1994) have suggested the possibility of life in the subsurface of Mars. Lava tubes provide an excellent analog for the study of life on Mars, not only because there are known lava tubes on Mars (Boston 2003), but because the tubes provide access to the subsurface, where cracks, fractures, and voids of all sizes may exist and may provide hospitable and protected conditions for microorganisms. Investigation of these environments on Earth is therefore important for creating the tools and techniques for detecting life on Mars and other extraterrestrial environments. Lava tubes contain frequent occurrences of biofilms called "lava wall slime" that represent an untapped resource for detecting and characterizing life in the subsurface (for example Northup *et al.* 2004). The existence of subsurface caves or voids that could provide similar geological environments on Mars is likely, based on the evidence for young lava flows (Boston 2003; Boston *et al.* 2003, 2004). The evidence for transient or sustained sources of water throughout geological history for such environments on Mars has become dramatically more likely with several recent discoveries on Mars.

The work of Boston *et al.* (2001) is establishing a suite of biosignatures from cave studies that will help guide life detection on Mars and other extraterrestrial bodies.

Opportunities: Using Studies of Microbes in Caves to Captivate Young Learners

To primary school students and young adults, caves are particularly intriguing and fun. We are using the results of our scientific studies in caves to create Web-based content available to students through formal education avenues and informally through home access to the Internet. We began by creating a Web site for our team, the **S**ubsurface **L**ife **I**n **M**ineral **E**nvironments (**SLIME**) Team (www.caveslime.org). This Web site provides information about studies being conducted by the SLIME Team and findings of interest (we hope) to others. One of the ways we are expanding the site involves a collaboration with Janet Shagum, a microbiologist and instructor for the science writing course in the English Department at the University of New Mexico. Her students write new material for the Web site after interviewing project scientists. For example, in the spring of 2005 one of the students wrote a story of Penny Boston's experiences in the Mars Simulation in Utah. The students write creative pieces that provide good, popular science looks at the research going on in caves and associated habitats.

Another venture as been the collaboration with the EPSCOR program to create a Virtual Center for the Environment (http://vce.inram.org/), which included a Cave Journey (www.caveslime.org/cavejourney). The Cave Journey includes content written by Northup and Tamara Montoya, a professional writing staff member of EPSCOR and features information about the earth and life sciences of New Mexico caves. The content is keyed to New Mexico Science Benchmarks and Standards and includes activities for teachers or parents, which were written by New Mexico high school teachers Patsy Jones and Ray Bowers. For students, there are also species accounts, a photo gallery of cave biota and speleothems for use in presentations, and a glossary of terms used in the Web site content. Initial response of New Mexico high school teachers attending a workshop on the Cave Journey was enthusiastic. The results coming out of cave research represent an exciting way to interest young adults in learning about caves and science through caves. An important way to create a desire to protect and conserve caves is to demonstrate their intrinsic fascinating nature.

Challenges: Moving Beyond Who's Home Studies

Learning "who's home" using advanced molecular biological techniques and targeted enrichment cultures is an essential first step in studying the microbiology of caves. As discussed elsewhere in this paper, there are a plethora of studies of geomicrobiological interactions in caves being conducted, which are filling in this portion of the picture of how microorganisms function in the ecosystem. However, it's also time to beef up studies of the role of microorganisms in non-geomicrobiological ecosystem functioning. Key areas in need of further investigation include microbial transformations associated with water and caves and the interactions between geochemistry and microorganisms; the role of microorganisms in cycling carbon, nitrogen, and phosphorus in the subsurface environment of caves; microbial interactions within communities (competitive versus mutualistic interactions); the nature of microbial food webs; and important applied studies of how various anthropogenic impacts on karst systems affect microbial communities in the subsurface. The exciting part is how many interesting studies remain to be done; the challenging part is how many interesting studies remain to be done.

Challenges: Culture-independent versus culture-dependent studies

Scientists have discovered that we are able to grow in culture less than one percent of the organisms that are in the environment using standard culturing techniques (Amann *et al.* 1995). Several cave microbiologists have done significantly better than this by adapting their media recipes to the cave environment in which microorganisms live (Rusterholtz and Mallory 1994; Boston *et al.* 2001; Spilde *et al.* 2005). This represents what Boston calls the "Keeping the Zoo" part of cave microbiology. Molecular phylogenetic techniques have allowed us to significantly expand the groups of organisms found in caves as discussed elsewhere in this paper and have been a welcome addition to microbiologists' bag of tricks. By extracting DNA from the environment, amplifying the DNA to yield millions of copies of particular genes, cloning and sequencing, one can obtain a much less biased view of what microorganisms are present in a particular cave environment. There are relatively new community fingerprinting methods that allow us to compare communities and their biodiversity, another extremely valuable tool. These techniques are, however, more costly by orders of magnitude than are traditional enrichment culturing techniques.

We have developed an interleaved strategy that begins with initial molecular biological characterization to characterize genetic sequences of microorganisms present. These results then guide culturing efforts and allow us to learn more about the physiology and biochemistry of the microorganisms present. These cultures are then fingerprinted using the community molecular techniques to determine which enrichment cultures are worth characterizing with molecular techniques. Microcosm studies in which we mimic conditions present in the cave environment from which the microorganisms came further help us study the roles that these microorganisms are playing. You really need both culturing and molecular techniques, with geological techniques thrown in where needed, to answer many basic questions

Challenges: Funding

One of the biggest challenges is cave microbiology work, as in other fields, is funding these studies. Molecular biology, geochemistry, and imaging techniques are expensive. On the positive side is the successful funding of several cave microbiology proposals by the National Science Foundation in the last decade. However, funding is becoming much tighter and we must become innovative in exploring new funding sources and selling the importance of karst studies. Karst scientists must become experts in promoting the public understanding of the value of karst. Also, it is our hope that the

National Cave and Karst Research Institute will provide a strong lead in identifying and helping to create new funding sources.

Challenges: Need for New Microbial Speleologists

As established karst scientists gray, it's important to replenish and expand the work force to study these fascinating microbial systems. Things have improved on this front and there are now strong cave and karst academic programs at Western Kentucky University, University of South Florida, and New Mexico Tech. New researchers are now on faculty at other universities and are working to establish cave and karst programs. To retain students graduating from these programs in the field, jobs and opportunities to work and publish must be available, which will require efforts by established karst scientists to serve as grant reviewers, spokespeople for karst, and associate editors of karst and non-karst journals. As mentioned at the recent NCKMS symposium in Albany, we need to become leaders with the responsibility and authority to be able to promote karst and cave sciences.

Challenges: Need for Best Practices

Rusterholtz and Mallory (1994) pioneered the idea that microbiological studies in caves needed to go beyond the traditional methods. They established that inoculating and incubating microbial cultures on site in caves is critical to being able to grow the more indigenous species of microorganisms. The removal of samples from caves for inoculating in the laboratory almost always guarantees that you'll be growing the weeds and the organisms that were likely transported into the cave by humans. Studies by Boston *et al.* (2001; Spilde *et al.* 2005) have shown the value of making low-nutrient media using water from the cave and rock dust from similar parent material as cave walls. When samples are removed for DNA extraction, some researchers believe that it's important to keep the samples on dry ice or in sucrose lysis buffer. Some of these strategies have been tested in the laboratory while others are based on experience and intuition of researchers. We need rigorous testing of various methods with subsequent publication of results. The National Cave Karst Research Institute will be taking the lead on sponsoring best practice workshops to bring experts together to hash out these proposed best strategies.

Summary

Microbial speleology provides a range of interesting and productive opportunities for expanding karst and cave sciences. We are discovering that many new microbial species can be identified from caves; evidence from Mallory and others (unpublished data) has revealed that many of these species produce useful chemical compounds of interest to pharmaceutical scientists. Molecular techniques can be applied with great success to cave microbial studies, greatly expanding our ability to accurately characterize microorganisms present in caves. These techniques and others are being used to expand our knowledge of how these newly identified microbial species interact with mineral surfaces, helping to precipitate and dissolve rocks in caves. Life detection on other planets is being aided by studies of cave microbial communities, which identify biosignatures for extant and extinct life in the subsurface. All of these studies provide rich fodder for education initiatives that use caves to teach earth and life sciences to children and the general public. Learning science through learning about caves is fun and exciting and you don't even have to get dirty if you use the Internet! All of these exciting opportunities also represent challenges as we work to expand funding and to recruit new scientists to the karst programs. We must expand existing studies into more aspects of how microorganisms function in the ecosystem and must determine the best practices for microbial work in the subsurface. We've got our work cut out for us, but we have an amazing array of opportunities in the field of microbial speleology.

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CRITICAL ISSUES IN CAVE BIOLOGY

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Abstract

I shall discuss the most critical issues in North American cave biology, particularly those related to conservation and cave management. The major impacts on cave life have been caused by water projects, land development, quarrying, killing and disturbing animals, sedimentation, contaminants, and nutrient loss and enrichment. Less obvious impacts are trampling, cave invasions by exotic and pest species, and isolation of caves by various activities.

The most dramatic declines in macroscopic cave faunas were caused by the direct disturbance and killing of bats and massive kills of stygobites from water projects, sewage, and chemicals. Perhaps six cave species became extinct as a result of human activities, but other extinctions may have occurred. Many species of bats, cavefishes, and crustaceans cannot be found in their historic sites today. The subtle and inexorable decline of some cave communities over decades may go unnoticed because of a lack of baseline surveys and systematic monitoring.

Although many plans have been written and 36 cave species are under federal protection, many other cave species are threatened by human activities. We are hampered by a lack of scientifically-trained manpower, the Taxonomic Crisis, the Vertebrate Bias, and pressure on caves by increasingly mobile trespassers, looters, and uninformed recreators. We need better baseline data and census methods, regional and national surveys, and cave protection methods. Bats and groundwater are the most critical biological issues, while jobs for cave biologists and taxonomists are probably the most critical related human-resource issues.

Introduction

In this paper I shall discuss the most critical issues in North American cave biology, which are echoed in many parts of the world (Elliott 2000, Hamilton-Smith and Eberhard 2000, Juberthie 2000, Tercafs 2001). Although theoretical issues in biospeleology are interesting and challenging, I shall focus more on conservation and applied cave management.

The Critical Issues

The critical issues in cave biology, which I shall elaborate below, are (1) threats to biodiversity, (2) pressure on caves and cave life, (3) the Taxonomic Crisis, (4) the Vertebrate Bias, (5) the need for better census methods, (6) insufficient work force of cave biologists, and (7) insufficient funding.

Threats to Biodiversity: Caves have many endemic troglobites and stygobites (obligate cave dwellers), and cave-dependent species, such as certain bats. Cave biologists are still finding new species and there is a huge backlog of undescribed species. The first endangered species ever listed in the USA was the stygobitic Texas blind salamander, *Typhlomolge rathbuni*, in 1967. In 2000 there were 25 listed cave species. In 2005, 36 (3%) of the 1,155 worldwide animals on the federal endangered and threatened list were cave dwellers, and all the listed cave species were from the USA. More cave forms are listed every few years; none have been "de-listed." The gray bat, a key species in eastern caves, is being considered for "down-listing" from endangered to threatened because of success in restoring some of its cave roosts, but a lack of good census data delays the down-listing. New listings tend to occur with rare, endemic forms endangered by urbanization. However, the latest listing, Tumbling Creek cavesnail, in 2001, is a species that is nearly extinct, probably because of sedimentation from a neigboring farm (Elliott *et al*., 2005). Perhaps six cave species became extinct as a result of human activities, but other extinctions may have occurred (Table 1).

Pressure on caves and cave life: The major cave impacts were reviewed by Elliott (2000):

(1) hydrological threats, (2) land development, (3) killing, over-collecting, and disturbing bats and other species, (4) sedimentation and contaminants, and (5) nutrient loss and enrichment. Less obvious are impacts caused by (1) exotic and pest species, (2) trampling, (3) isolation of caves by quarrying, mining, and land development.

The Taxonomic Crisis. If we do not know our biodiversity, we cannot conserve its components well. There are not enough taxonomists to describe new-found species to keep ahead of habitat destruction. Many think of this taxonomic crisis as happening only in the tropics, but it is affecting our temperate-zone caves and other habitats.

Wheeler, Raven, and Wilson (2004), three famous names in biology, published an important editorial on "Taxonomy: Impediment or Expedient?," from which I quote:

> Society has a growing need for credible taxonomic information in order to allow us to conserve, manage, understand, and enjoy the natural world. At the same time, support for taxonomy and collections is failing to keep pace. Funds nominally allocated to taxonomy go largely to reconstruct molecular phylogenies, while thousands of species are threatened by imminent extinction. Ecologists working in the tropics have felt this lack of taxonomic knowledge as an impediment that inhibits their ability to analyze community-level phenomena. It is time to evaluate the sources of this impediment and address them. Taxonomy must facilitate, not obstruct, biodiversity studies and conservation.

Some funding is available for biodiversity and taxonomic studies, including the U.S. Fish and Wildlife Service and states for recovering listed species, State Wildlife Grants (federal funding), National Science Foundation grants for training taxonomists and bioinventory, The Nature Conservancy, the U.S. Department of Defense's Legacy Resource Management Program, and others. Since 2003 the Legacy Program has co-sponsored the publication of 18 new cave species described from two Army bases in Texas. Currently, taxonomy is being done less in academia and more by natural history museum taxonomists and free-lance taxonomists supported by small grants and contracts from public agencies and private foundations.

The National Science Foundation offers **PEET** grants (Partnerships for Enhancing Expertise in Taxonomy) to support competitively reviewed re-

Species	Last Year Seen	Threats	Range
Crustacea			
Bactrurus n.sp., amphipod	1963	sealed spring, pesticides	Indiana
Stygobromus lucifugus (= *subtilis*?), Dubious Cave amphipod	1882	?	Illinois
Orconectes sheltae, Shelta Cave crayfish	1988	loss of nutrients	Alabama
Insecta			
Pseudanophthalmus krameri, Kramer's cave beetle	1973	?	Ohio
Amphibia			
Eurycea robusta, Blanco blind salamander	1948	hydrologic changes?	Texas
Eurycea troglodytes, Valdina Farms Sinkhole salamander	1985	recharge dam	Texas

Table 1. Possibly extinct troglobites in the USA.

search projects that target groups of poorly known organisms. This effort is designed to encourage the training of new taxonomists and to translate current expertise into electronic databases and other formats with broad accessibility to the scientific community. For example, some funding has been used for taxonomic work on millipedes (Milli-PEET project) and amphipods. In the USA, four new professional systematists (taxonomists) are working on these groups, but only about half of the graduate students who entered these programs are still working taxonomists; the others shifted fields to more lucrative positions.

National Science Foundation's grant program, **Biodiversity and Inventory**, is not sufficiently funded for the number of qualified applicants. An important proposal for cave biology work in eight Appalachian states, involving a group of cave biologists and invertebrate taxonomists, was rejected twice, despite favor from state Natural Heritage programs (John Holsinger, pers comm).

Many invertebrate taxa have few or no taxonomists, and American cave biologists increasingly seek collaboration with scattered experts worldwide. Examples of taxa with few taxonomists are:

Platyhelminthes (flatworms), primitive insects (springtails, diplurans), Orthoptera (crickets), Chilopoda (centipedes), Diplopoda (millipedes), Arachnida (spiders, mites, scorpions, pseudoscorpions, and the like), and many crustacean groups.

The Vertebrate bias: The Taxonomic Crisis is supported in part by the Vertebrate Bias. Federal and state agencies have spent more on studying and protecting vertebrates, like bats and cavefishes, than on invertebrates. Thirty years ago the U.S. Fish and Wildlife Service was reluctant to list cave invertebrates. Now cave and spring species are among the most prominent invertebrates on the list because of their high endemism and vulnerability (Figure 1).

The Vertebrate Bias is obvious to biologists like me, who were trained in entomology, arachnology, invertebrates, and vertebrates. This bias is the unfortunate tendency by some to show more interest in the conservation of vertebrates, especially mammals and birds, than of invertebrates. The basis for the Vertebrate Bias bias is partly educational, partly aesthetic, and sometimes is based on the false assumption that ecological importance is related to body size or relatedness to humans. Probably 99% of animal species, and thus much of the web of life,

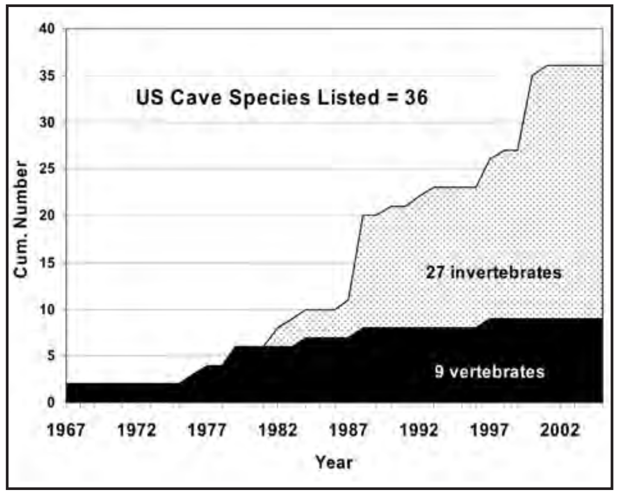

Figure 1. Comparison of endangered species listings of cave vertebrates and invertebrates.

are invertebrates, but we too often concentrate our conservation efforts on vertebrates. Native plants get even less respect.

The Vertebrate Bias appears to be declining in the listing process for endangered species, but the funding of wildlife preserves is still vertebrate-oriented (Elliott 2000, Figure 1). Nine cave-adapted vertebrates (not including bats) have been listed since 1967, none since 1997. Cave invertebrates were listed starting in 1982, and continue to be listed until now we have 27. This increase is despite a recent trend to toughen listing requirements and require more scientific documentation before listing, which indicates a real environmental crisis developing.

In the late 1970s many government biologists were old-school "wildlifers" with a strong vertebrate bias, in my opinion. I worked in California under a contract for the U.S. Army Corps of Engineers to rescue a tiny species of cave harvestman, *Banksula melones*, from extinction, thought to be imminent from quarrying and the newly constructed New Melones Reservoir (Elliott 1978, 2000). The Corps wanted to avoid a listing of this arachnid. A representative of the U.S. Fish and Wildlife Service was quoted in the press as saying that listing a "spider" was not worth the Endangered Species Act. (This statement was doubly ignorant because harvestmen are not spiders, but they are arachnids. His gaffe was as unschooled as calling a bat a rodent.) However, by 1988 six cave invertebrates were listed from the Austin, Texas, area, and soon nine more cave invertebrates were listed from the San Antonio, Texas, area. These listings were initiated by concerned conservationists, cavers and speleologists, and they were not resisted by the U.S. Fish and Wildlife Service (Elliott 1978, 2000). In 2002 the Tumbling Creek cavesnail was listed from Missouri, and this time the process was initiated by a Fish and Wildlife Service scientist (McKenzie 2001).

The need for better census methods: Baseline cave biology surveys are needed to assess impacts on caves and their wildlife. We also need bioinventories led by professional cave biologists, bat surveys using improved census methods, cave life databases, heritage databases and state cave surveys that collaborate with qualified researchers, cavers and conservation planners. In this Symposium, see Elliott *et al*. for a paper on the "Missouri Department of Conservation Method" for counting bat emergences from caves, page 147, (also see Elliott 2005). We need new technology and reliable methods, with statistical estimates, to monitor population trends in cave species, especially bats, which may be keystone species in providing nutrients to cave communities. If we are having success in restoring and stabilizing gray bats, we need at least five years of good data before the U.S. Fish and Wildlife Service can make a case for down-listing them from endangered to threatened status (Paul McKenzie, pers comm). Censusing cavefishes and invertebrates is difficult because of limited access and low numbers; we wish for better technology to solve this problem, such as down-hole video cameras, small sensors and data loggers, and cheap, reliable photography.

Insufficient work force of cave biologists: Currently we have a fair number of young bat biologists in the marketplace, who are needed in universities, environmental consulting, wildlife agencies, nonprofit conservation groups, and other organizations. However, we have relatively few young cave biologists because of the few jobs. Academic cave biologists must do a variety of teaching and research tasks, and their jobs usually are not billed as "cave biologists." We still have many undescribed invertebrate cave species, but few young biologists are being trained in invertebrate taxonomy so they can identify or describe them. Federal and state land resource agencies hire bat biologists and cave specialists, but few full-time cave biology jobs have been created. However, such agencies need cave biologists for applied research and resource management. In the last 20 years a small number of consulting cave biologists have gone into business, but it is difficult to make a living from sporadic projects. We need more federal and state emphasis on hiring cave biologists, not just cave specialists and bat biologists.

Insufficient funding: Low funding for cave biology is apparent in the problems outlined above. Funding is adequate for some projects, ironically at some military bases. About $1 million has been spent over 12 years to find and research caves and cave fauna at two Army bases in Texas (George Veni, pers comm). I participated in this work (Elliott 2004). There is an ironic trend in the USA, that military bases are now some of the last bastions of endangered species, simply because they are often the only remaining large tracts of wild land in many regions. Despite the fact that they may be used for infantry training grounds, small arms fire, tank fire, artillery, and bombing ranges, somehow endangered species like the black-capped vireo and certain cave beetles survive there. Perhaps urbanization is more damaging to our natural heritage than soldiers. We know more about cave fauna on some Army posts than on many national forests, conservation areas, and private lands.

Final Thoughts

We need regional and national biogeographic research, biodiversity analyses of caves, and rating of caves for multiple natural resources and threats against them. General cave biology and cave microbiology would be part of the whole mix. Wildlife agencies put more emphasis on biological resources, but they can work with other organizations to consider all cave resources. For example, the Missouri Cave Protection Working Group is using a spreadsheet method for rating caves for protection based on multiple resources.

Cave protection methods are increasingly sought by landowners and managers. In Missouri and other states, cave owners are increasingly asking for assistance to protect, restore, and gate caves (Elliott 2004b). A demographic change is occurring as baby-boomers retire and buy land; many of them are more conservation-minded than the previous generation.

Cave microbiology may or may not be a useful indicator of human impacts on a cave because

(1) many caves are already well traveled, have surface organic inputs, or are contaminated, (2) many caves have endemic cave animals, but few known, unusual, or endemic cave microbes, (3) cave microbes cannot be seen or identified by most cave visitors, and (4) no cave microbes are protected by law (yet).

Many cave animals are vulnerable to overuse, disturbance, pollution, and the like. Cave microbes may or may not be so sensitive. However, certain telltale microbes are useful for gauging visitation rates by humans and as indicators of pollution.

Bats and groundwater are highly critical biological issues. Bats have high economic and ecological value because they consume night-flying insects, some of which are pests. Corn earworm moths are consumed by several species of bats, most notably the Mexican free-tail. About half of the 42 species of U.S. bats use caves during their life history. In major karst areas, like the Edwards Aquifer of central Texas, the Ozarks, the Appalachians, and the Interior Lowland Plateaus of Kentucky and Tennessee, karst groundwater resources have major economic and health importance (even for those uninterested in caves *per se*). Bats and groundwater are also critical to the health of cave ecosystems.

In the final analysis, jobs for cave biologists and taxonomists probably are the most critical human-resource issues related to the problems discussed above. Important as they are, only so much work can be accomplished by volunteers and generalists. A scientifically trained, professional work force is needed to carry out the biological work that needs to be done.

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BACTERIA AS INDICATORS OF HUMAN IMPACT IN CAVES

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Abstract

This project used select microbes as indicators of human impact in caves by culturing in areas with a range of visitation impacts. Human Indicator Bacteria are those that would not normally be present in a cave unless there has been substantial impact by humans in terms of presence, activities, or pollution. Preliminary study of Human Indicator Bacteria in Lechuguilla Cave compared low impact (alcoves, off-trail sites, non-drinking water pools) with high human impact areas (camps, trade routes, rocks that humans slither over, urine dumps, drinking water sources). Enrichment culture procedures targeted high-temperature *Bacillus* spp., *Escherichia coli*, and *Staphylococcus aureus* sampled from these sites. The study was recently expanded to Mammoth Cave and included fungi, with additional study planned in Carlsbad Caverns and Spider Cave. There is variation by cave, but our results show increased levels of *Staphylococcus aureus*, *E. coli*, and high-temperature *Bacillus* in areas with the greatest visitation levels in both wild caves and commercial caves, although recovery rates were very low at Mammoth. A reduction in numbers was seen in Lechuguilla with *S. aureus* and *E. coli* if the areas are given a rest from human visitation. Survival of Human Indicator Bacteria under idealized lab conditions in a variety of cave soil types showed that *S. aureus* died off within two to four weeks. *E. coli* K survival was similar, but varied, and increased in numbers in some soils. Bacteria can be used as indicators of human impact in caves and as such, provide cave managers with a useful tool to measure human impact.

Introduction

Human Indicator Bacteria are those that would not normally be present in a cave unless there has been substantial impact by humans in terms of presence, activities, or pollution. We know from studies of lint deposition that visitors can leave behind a mix of biodegradable and non-biodegradable materials (Jablonsky, Kraemer, and Yett 1995). These organics provide new microhabitats and nutrients that can support the growth of contaminating microbes, and even alter the underlying surface.

The microbes used in our studies are *Staphylococcus aureus*, a member of the normal flora of skin; *Escherichia coli*, a normal inhabitant of the digestive tract of warm-blooded animals; and high-temperature *Bacillus*, found in soils heated by sunlight. Limited additional work was done with fungi. Fungi are limited to areas contaminated from the surface, and require large inputs of organic matter (Dickson and Kirk 1976). We expect that human impacts will vary in different environments, and report on studies from two very different locations, Lechuguilla Cave in Carlsbad Caverns National Park, New Mexico, and three locations in Mammoth Cave National Park, Kentucky: Great Onyx Cave, Historic Mammoth Cave, and the Frozen Niagara–New Entrance area. Information will be used to improve the scientific information base to allow for informed management decisions.

Studies of microbes in caves are limited due to the technical difficulties of studying organisms that can't be seen. Comparisons of cave soils with surface soils were done by Gounot in 1967 at the CNRS in France. She compared the numbers of bacteria culturable from cave silts compared to rich agricultural land. Cave soil bacterial counts tended to be lower, yielding several million per gram, while the agricultural soil bacterial counts yielded several hundreds of millions from a gram. Most other studies have supported her general conclusions. Many studies of microbes in caves have relied on limited plate count methods, which greatly underestimate the total population and tell us nothing about the activity of the microbes in that environment. Culture techniques work best for non-resident microbes, including the human indicator microbes reported on in this study.

Studies of the biomass and activity of microbes in limestone caves in Kentucky were conducted by Feldhake (1986). He concentrated his studies on actual measurements of microbial metabolic rates in 12 sites in four caves, along with comparisons to overlying forest soils. Except for a site rich in cricket guano, Feldhake found that organic matter content, microbial activity, and biomass was much lower in the cave than in forest soil. He also found significant variations among sample sites within the cave, and methodological problems when samples were removed from the cave, transported to the lab, and assays were attempted more than 24 to 48 hours after collection.

One notable exception to studies that show low numbers and activity of microbes in caves has been work done by Mallory and his students. A major study compared the microbial activity, density, and diversity in two aquatic sediment sites in Mammoth Cave (Rusterholtz and Mallory 1994). The study included counts of cells in the sediment, staining to determine metabolic activity of soil microbes, plate counts using both high and low nutrient media, followed by extensive physiological testing of isolates from the plate counts. They recovered between 11 to 58% of the total cell count on culture medium. The recovery rate for most surface soils is typically 0.4 to 1.7%. They also detected active metabolism in 53 to 58% of the population, despite very low nutrient levels of total organic carbon per liter of water. The diversity of populations was extremely high, with 42% of the isolated species similar to surface organisms, and the remainder unidentified. There were no dominant species, and the type of growth medium used strongly influenced the types isolated.

Studies of bacteria and fungi in Lechuguilla Cave by Northup and others (Northup *et al*. 1992, 1995, 2003; Mallory, Spokas, and Northup 1995, Cunningham *et al.* 1995; Spilde *et al*. 2005) from a variety of habitats, including sediments, pools, speleothems, and speleosols (corrosion residues), show microbial communities that are indigenous to the cave. These microbes are adapted to extremely low nutrient conditions. Chemolithotrophs were suggested to play important roles in formation of speleosol deposits in Lechuguilla. The report expressed concern about the potential of increasing inputs of organic matter into the pools to protect the native oligotrophic bacteria and provides suggestions for limiting human organic input. Northup's suggestion for establishing "microbial cave preserves" would allow for study of indigenous populations of microbes without human impacts. Application of new molecular biological techniques pioneered by Norm Pace is revealing potentially novel bacteria that may serve as a marker for native cave microbial communities (for example, Barton *et al*. 2003).

Northup (1997) *et al*. (1997) studied the same three groups of organisms on which we focus in this proposal in high and low impact areas in Lechuguilla Cave. They found significantly more Human Indicator Bacteria in the high impact areas. A major focus of her work is seeking the balance between cave exploration and scientific discovery, particularly in terms of human introduction of non-indigenous microorganisms and organic carbon.

The situation in Mammoth Cave is very different. Mammoth has multiple entrances, high visitation by tourists, and significant impact by water from the surface; pristine areas are few. Studies of unique communities are limited to studies of microbes in saltpeter soils (Hill *et al.* 1983, Olson and Krapac 1997).

The objectives of this study are:

A. Can numbers of Human Indicator Bacteria (*S. aureus*, *E. coli*, and high-temperature *Bacillus* spp.) be used to compare the impact of humans in caves (Lavoie and Northup, 2002)?

B. How long will Human Indicator Bacteria survive when added to a range of cave soil types?

Due to the complexity of microbial communities and the specialized techniques for their study, development of an Index of Biological Integrity (IBI) to assess the impacts of humans on cave microbes has not been developed. This study will provide important baseline information on the feasibility of detecting a select group of bacteria that may be able to serve as indicators of human presence and activity, using simple and relatively inexpensive techniques. These Human Indicator Bacteria were detected and quantified in areas known to have high human impact compared to areas with low human impact in both Lechuguilla Cave and Mammoth Cave. The survival of indicator bacteria will be modeled in the lab. We will extend this study to Carlsbad Caverns and Spider Cave at a later date.

Material and Methods

Description of study areas:

Lechuguilla Cave is a largely pristine cave environment, with one small entrance and has limited and highly regulated visitation. The cave is in a desert region, protected by a siltstone caprock, with very low surface impacts from water (Davis 2000). In an attempt to preserve the cave and native microbial communities, expeditions utilize flagged trails and established camp areas with defined drinking pools and urine dump areas. The study compared low-impact areas off-trail, in alcoves, and drinking water pools with high-impact sites in camps, trade routes, trails, urine dumps, and drinking water pools in the East, West, and Southwest Branches. A particular branch was placed off-limits to exploration for a month following each sampling, allowing comparison of Human Indicator Bacteria during typical visitation impacts and after a recovery period.

Mammoth Cave is in a temperate region with high levels of rainfall. There are multiple entrances, with large communities of invertebrates that can enter and leave the cave on a daily basis. The study sites in Mammoth Cave are all associated with tourist trails, and have variable levels of visitation. All of these locations are also frequently impacted by water from flooding or direct surface inputs. Great Onyx Cave is visited by an average of 36 people per day during the summer months. The cave branches, and tourists are limited to one branch, allowing for comparison of high and low impact areas in an environment that largely has low impact. The Frozen Niagara–New Entrance is visited by an average of 847 people per day in the summer. Directly adjacent to the Frozen Niagara formation is a drop down into a very seldom visited area named the Radio Room, again allowing for a high and low impact comparison. The Historic Mammoth Cave receives an average of 1,002 people per day in the summer that all pass through the Rotunda on their way to different destinations within the cave. We sampled from the Historic Tour route, and used areas off the trail in branch passages for low impact comparison.

Sampling, Plating, and Incubation:

Objective A. Human Indicator Microbes. Swabs of defined areas (1 cm^2 areas and later 10 cm^2) were collected from a range of locations with high exposure to humans and low exposure in both Lechuguilla Cave and the Mammoth Cave National Park sites (see Results). Samples were plated on EMB agar, Mannitol Salt Agar, and Sabaroud Dextrose Agar (Mammoth Cave sites only) for detection of *E. coli*, *S. aureus*, and fungi, respectively, with incubation at 37° C. Lechuguilla samples were inoculated in Brilliant Green Bile Broth with Durham tubes (Difco) onsite and transported to the lab where they were monitored for gas production. Those that were positive for gas production were plated on EMB agar and monitored for production of the characteristic metallic-green sheen of *E. coli*. High salt media was used to enrich for *S. aureus,* which is highly resistant to high-salt content media, in Lechuguilla samples; those that showed growth were subjected to a coagulase test to confirm the presence of *S. aureus*. To test for high-temperature *Bacillus* spp., Lechuguilla swab samples were inoculated into sterile distilled water and heated in 70° C for 10 minutes on-site and transported to the lab where they were plated onto Antiobiotic Medium 1 (Bacto) and incubated at 45° C. Mammoth swabs were heated at 65° C for ten minutes to kill most bacteria, and plated on Nutrient Agar or Nutrient Agar with antibiotics added, and incubated at 45° C for detection of high-temperature *Bacillus*. Samples from Lechuguilla Cave were incubated in the cave for a minimum of 24 hours prior to removal to the surface for incubation. Samples from Mammoth Cave were brought to the surface, plated, and incubated.

Objective B. Survival. This part of the study has been done so far only for the Mammoth Cave sites. Soil samples were collected from appropriate locations to represent a range of typical cave soil types. We aseptically collected approximately 150 g of clay-silt mud from the right hand passage in Great Onyx Cave, sand near Bubbly Pit in Great Onyx, gypsum from the Great Kentucky Desert of Great Onyx Cave, and saltpeter soil from the Rotunda in Historic Mammoth. Except for the mud, soils were screened to remove large materials, which were left *in situ* to minimize disturbance in the area. Soils were refrigerated and returned to the lab at Plattsburgh State University.

We set up three replicates of each soil using 60 g of soil and 120 ml of water mixed in a 250 cc Erlenmeyer flask. We marked the level of the water line in each flask for future adjustments. Each soil type was plated to test for the background level of *S. aureus* and *E. coli*. One set of each soil type was inoculated with *Escherichia coli K* and one set with *Staphylococcus aureus*, and incubated at room temperature. At regular intervals (24 hours and then weekly) each microcosm was cultured using appropriate dilution and spread-plating in triplicate onto EMB Agar for *E. coli*, and Mannitol Salt Agar or Nutrient Agar with 20% added NaCl for *S. aureus*. Plates were incubated at 37° C for 24 hours before counting individual CFU. We continued this until the bacteria are below the limits of detection.

Results

In Lechuguilla, *E. coli* were recovered only from urine dumps and urine control sites (Table 1). No pools were contaminated. *S. aureus* was found at a much higher frequency in high impact sites (Table 2). With both organisms the number of positive samples declined after humans were excluded from the area (Table 1 and 2). Results from Mammoth Cave are presented in Table 3. The difference in number of colonies of *Bacillus* spp. between low and high human impact areas in Lechuguilla Cave was marked. On average there were 56.4 colonies from samples from high human impact areas (trails and camps) and 4.60 colonies from low human impact areas (off trail, alcoves), a difference that is statistically significant.

Table 1. Lechuguilla sites contaminated with *E. coli* by impact level, comparing the initial sample and the results post-exclusion. Numbers in parentheses indicate total number of sample sites.

Impact Level	Initial Sample	Post-exclusion
Urine dumps	4 (18)	1 (12)
Urine controls (low impact)	1 (15)	1 (12)
Old urine dump	0 (15)	0 (6)
Drinking pools	0 (24)	0 (9)
Non-drinking pools (low impact)	0 (30)	0 (15)

Table 2. Lechuguilla sites contaminated with *Staphylococcus aureus* by impact level, comparing the initial sample and the results post-exclusion. Numbers in parentheses indicate total number of sample sites.

Impact Level	Initial Sample	Post-exclusion
High impact	13 (42)	0 (21)
Low impact	1 (36)	0 (21)

Table 3. Summary of the number of positive sites (total number of samples in parentheses) from Frozen Niagara, Great Onyx Cave, and Historic Mammoth Cave. High and Low impact sites. Samples are either 1 cm^2 or 10 cm^2. ND = not determined.

Frozen Niagara	E. coli	S. aureus	Fungi	HT *Bacillus*	
High 1 cm^2	2 (16)	1 (16)	5 (16)	ND	
High 10 cm^2	2 (10)	0 (10)	4 (6)	ND	
Low 10 cm^2	0 (10)	1 (10)	8 (10)	ND	
Great Onyx	*E. coli*	*S. aureus*	Fungi	HT *Bacillus*	
High 10 cm^2	1 (15)	1 (15)	8 (15)	1 (12)	
Low 10 cm^2	0 (14)	0 (14)	1 (014)	0 (12)	
Mammoth	*E. coli*	*S. aureus*	Fungi	HT *Bacillus*	HTB Count
High 10 cm^2	2 (15)	2 (15)	1 (15)	8 (9)	>500 CFU
Low 10 cm^2	1 (7)	0 (7)	0 (7)	5 (7)	5 CFU

Survival with time of *S. aureus* (Figure 1) and *E. coli* (Figure 2) in the different soil types from the Mammoth Cave sites show an initial rapid die-off. *S. aureus* were all gone or below the limits of detection in two to four weeks. *E. coli* showed a similar pattern, except for an apparent increase in numbers in three of the four soil types after two weeks.

Discussion

In Lechuguilla, urine dumps and urine control sites were the only areas where *E. coli* was recovered (Table 1). An old urine dump site and drinking and non-drinking pools of water were all negative. *S. aureus* was found (Table 2) at much higher frequency in high-impact sites (13 of 42 samples) compared to low-impact sites (1 of 36 samples). The numbers of contaminated samples decreased after a period of closure of the cave to exploration, indicating that these non-resident human indicator bacterial species die off over time.

The number of sites in Lechuguillla contaminated with high-temperature *Bacillus* was statistically significant, with the average number of colonies from high-impact sites 54.6 compared to only 4.6 at low-impact sites. These contaminant bacteria are expected to persist for years because of their production of highly environmentally resistant endospores.

Recovery rates for *E. coli* and *S. aureus* were low at all of the Mammoth Cave sites (Table 3), despite sampling immediately following tour groups in high-impact sites. Distinctions between low and high impact areas were weak. High-temperature *Bacillus* were almost undetectable in Great Onyx Cave. The cave receives very few visitors and visitors are dropped off by bus just a few feet from the entrance, and probably simply have no opportunity to pick up these bacteria from the soil and track them into the cave. The results at Mammoth Cave are simply confounding, with no real distinction in recovery between high and low impact sites, although the number of colonies was much higher in high-impact sites. We believe the situation merits further study. Our low-impact sites may have been too close to high-impact sites, allowing for contamination by air currents. There may also be fewer high-temperature *Bacillus* in the soils at Mammoth compared to the desert areas around Lechuguilla.

Preliminary work with fungi provided interesting results, with higher positive sites reported from Great Onyx and Frozen Niagara–New Entrance sites, which both have higher impacts from water. There was no distinction between high and low impact areas with Frozen Niagara–New Entrance sites, possibly reflecting the high surface impacts at all of the sites and proximity to entrances. The number of positives was much greater in high impact sites in Great Onyx Cave. Sites closer to the entrance are included in the high impact sites.

The low impact site is a side passage at the limits of the tourist trail. Results at Mammoth were very low, with no distinction between high and low impact sites.

We intend to follow-up at Mammoth with a survey of frequency of high-temperature *Bacillus* and fungi by distance into the cave. We will also conduct a similar study at Carlsbad Caverns.

Survival of *S. aureus* (Figure 1) and *E. coli* (Figure 2) bacteria with time was conducted in the lab using four soil types common in Mammoth Cave; a clay-silt mud, sand, gypsum, and saltpeter. *S. aureus* bacteria died off quickly in the first 24 hours to one week, then showed a lower rate of decline, and were below the limits of detection in two to four weeks. Survival was higher in saltpeter soil only. *E. coli* showed the same initial pattern of a rapid die-off in the first 24 hours to one week. Numbers were below the limits of detection in four weeks in the clay-silt mud soil. The three remaining soils had an unexpected increase in the number of cells after two weeks. These findings lend support to the results reported by Hunter *et al*. (2004) with further discussion by Barton and Pace (2005) and response by Hunter *et al*. (2005). We simply may not know how these bacteria behave in nature in contaminated ecosystems. This portion of the study will be repeated with soils from Carlsbad Caverns.

In summary, higher numbers of Human Indicator Bacteria (*E. coli*, *S. aureus*, and high-temperature *Bacillus*) are found in areas with greater human impact in Lechuguilla, with less distinctive results from Mammoth Cave sites. Recovery rates are higher in Lechuguilla possibly because of the intense, sustained impacts of people in camps, while human impact at the Mammoth Cave sites may be much more limited due to the rapid movement of visitors through the caves. Differences may also be due to temperature, moisture, and soil types. Given time with no humans present, the numbers of *E. coli* and *S. aureus* did die off at Lechuguilla. Laboratory microcosm studies show that *S. aureus* and *E. coli* are below the limits of detection in two to four weeks, with some influence of soil type. *E. coli* may be able to grow under field conditions with high levels of contamination to provide nutrients, contrary to expectations. Northup (1997) stresses the importance of maintaining low nutrient conditions to preserve native cave microbial communities.

Acknowledgements

This work was conducted in Carlsbad Caverns National Park with funding by the Charles A. and Anne Morrow Lindbergh Fund. The new studies

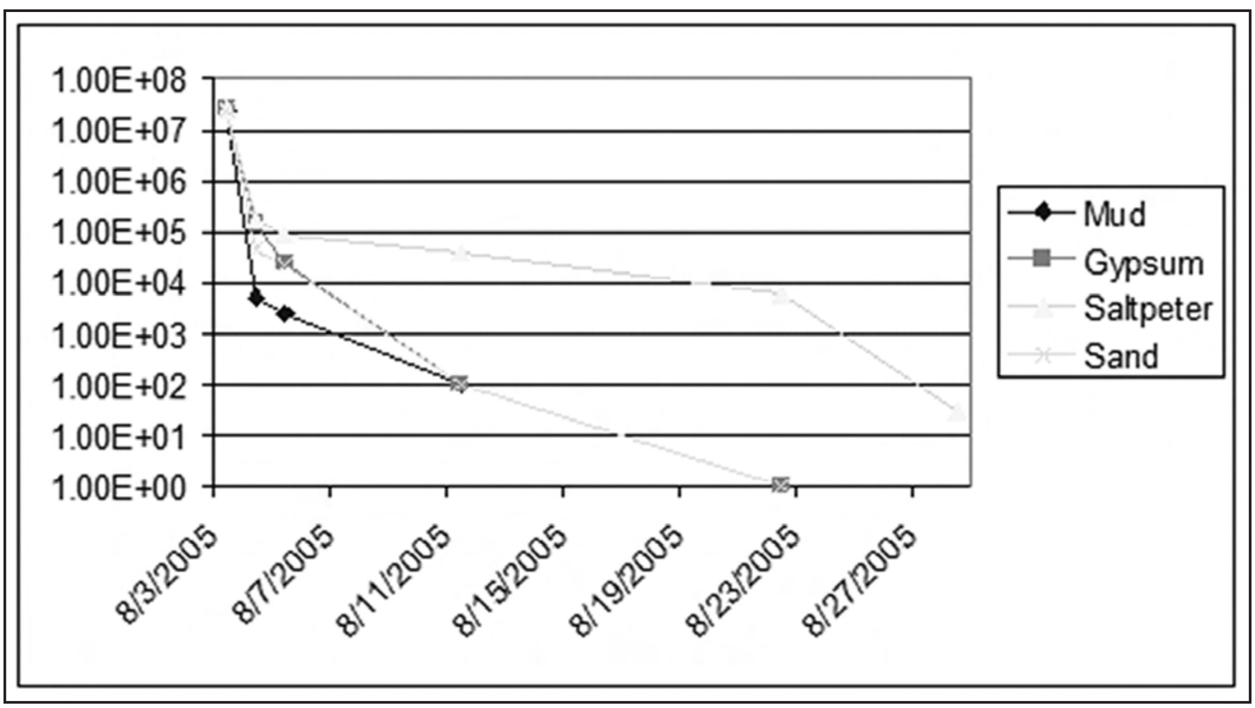

Figure 1. Numbers of S. aureus with time in different soil types from Mammoth Cave.

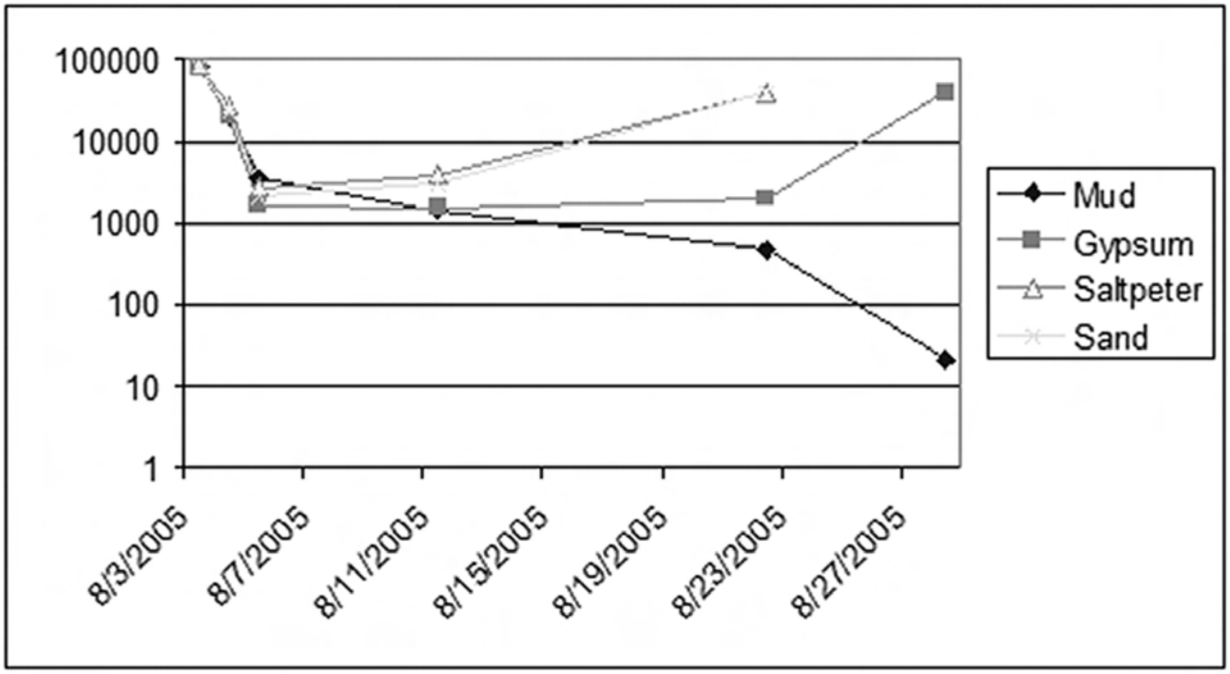

Figure 2. Numbers of E. coli with time in different soil types from Mammoth Cave.

are being carried out with support from T&E, Inc. Thanks to Larry Mallory for advice on media and other procedures. Kathleen Beck provided major assistance with the lab work in New Mexico. Work in Mammoth Cave National Park was done under RFP MACA-2005-SCI-0007. Plattsburgh State University student Sandra DeCoste provided assistance in the field and in lab. High school students Elizabeth Lavoie and Steven Jadzack provided field assistance at Mammoth Cave.

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MISSOURI'S CAVE FOCUS AREAS

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Abstract

In 2004 the author developed a set of "Cave Focus Areas" for the Missouri Department of Conservation's "Comprehensive Wildlife Conservation Strategy," using cave biodiversity values, important bat caves, cavefish sites, and major karst springs in a multidimensional GIS study. The basis of the study was the Missouri Cave Life Database. I shall discuss some aspects of the Database, which I developed with several contributing research partners. The Database is used for biogeographic and biodiversity analyses, checklists for cave studies, and the like. I derived 97 Cave Focus Areas, which became polygon shapefiles in ArcMap®. Each focus area takes in one or more caves or springs based on multiple scores. The Cave Focus Areas were melded into larger Conservation Opportunity Areas, and will include dye tracing studies, cave studies, cave management work, and cooperative work with private and public landowners.

Introduction

In this paper I will discuss how I developed a set of "Cave Focus Areas" for statewide wildlife planning within the Missouri Department of Conservation using data from several sources, and how the areas were integrated into Missouri Department of Conservation's "Comprehensive Wildlife Conservation Strategy."

Missouri karst lies mostly in the Ozark Plateau Region, but some caves are in the northeastern Hannibal Karst and the eastern St. Louis and Perryville karsts. The latter two areas can be considered a physiographic extension of the Interior Lowland Plateaus of Kentucky, Tennesee, and Illinois; indeed there are some cave biogeographic affinities with eastern American karst (Elliott and Ashley 2005). In Missouri, the St. Louis and Perryville karsts are classified ecologically as part of the Ozark Highlands (Nigh and Schroeder 2002). The Missouri Speleological Survey has recorded more than 6,000 caves, second in the USA after Tennessee.

Methods

I created the Missouri Cave Life Database (formerly the Missouri Biospeleological Database) in 1998 at the Missouri Department of Conservation to assemble all known species checklists and data sources on the subterranean species of Missouri into a relational database. The database, which is maintained in Microsoft Access®, can be used to produce checklists for any county or cave, or a list of caves for any species. The Cave Life Database is used for recording the many published and unpublished records from the scientific literature, agency reports, gray literature, databases, and unpublished records from reliable observers and biologists. The Cave Life Database is used for tracking field collections to museums and taxonomists, tracking trends in wildlife populations, biogeographic and biodiversity analysis, planning, updating the Missouri Natural Heritage Database, and education.

Currently the Cave Life Database contains data on about 1,150 caves, 107 "cave springs" (air-filled caves issuing springs), 147 other springs, six mines, six wells, and about 40 other sites. Represented are more than 12,000 observations and collections of 976 species, including 81 troglobites (Culver *et al.* 2003; Elliott and Ashley, 2005).

I developed a cave biodiversity index based on three elements: SR (species richness or number of species in the cave), T (number of troglobites or obligate cave-dwelling species, including stygobites, or aquatic troglobites), and SE ("site endemism," which is a measure of troglobite endemism or rarity on a statewide basis).

SE = ∑e where e (endemism) = 1/number of known Missouri sites

For example, the famous Grotto salamander, *Eurycea spelaea* (formerly *Typhlotriton spelaeus*), is the most widespread Ozark troglobite, with 173 known sites in Missouri, so

e = 1/173 = 0.00578.

In contrast, the Tumbling Creek cavesnail, *Antrobia culveri*, is a severely endangered species known from one cave, so

e = 1/1 = 1.00000.

Tumbling Creek Cave, has an SE value of 4.01, representing the aggregate endemism of 12 species of troglobites, at least three of which are unique to that cave. So, the more endemic a cave's fauna is, the higher the SE value.

To represent all three elements in one score for each cave I multiplied them to obtain

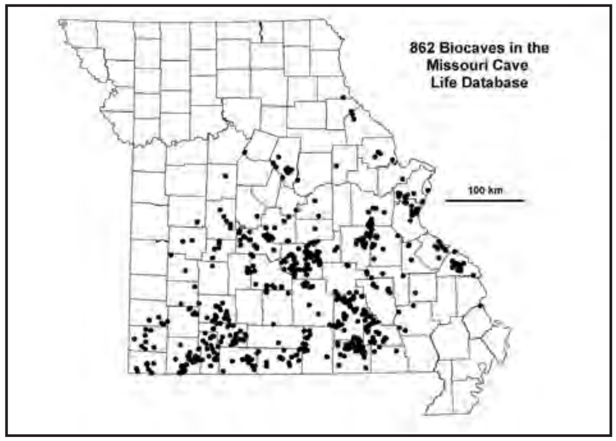
Biodiversity index = SR x T x SE

which I use for ranking important caves for biodiversity.

(One could add SR, T, and SE, however they do not scale the same. One could transform the SE value by multiplying by 10, to obtain a value range in the same order of magnitude as SR and T. However, then adding SR, T, and SE results in a index that ranks just the same as multiplying the three factors.)

In this study, the term "biocave" is a cave for which at least five species were recorded in the Cave Life Database. I considered five to be the minimum number of species indicating that there had been some bioinventory instead of a cursory check or a single-species survey. Beginning with a set of about 1,200 caves with biological records, I derived a subset of 862 "biocaves" (Figure 1).

The Cave Life Database does not contain geographic coordinates of caves. I relied instead on the Missouri Department of Conservation Cave Database (220 caves), Missouri Natural Heritage Database (200 important caves), and a partnership with the Missouri Speleological Survey (more than 6,000 caves), to which we contribute data.

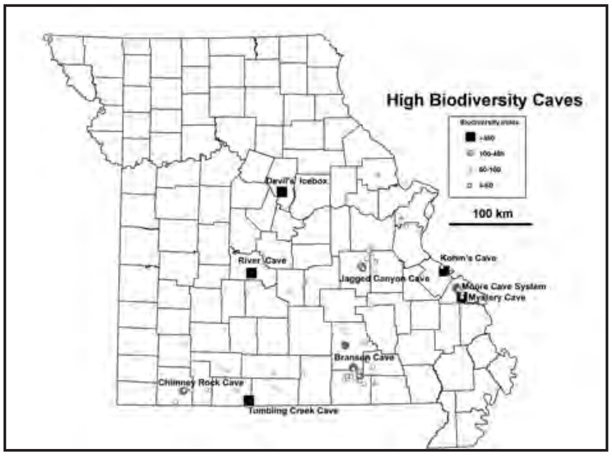


Fugure 1. 862 biocaves in the Missouri Cave Life Database. Over 6,000 caves are recorded in Missouri.

I temporarily created a relation between a table of biocaves and a table of cave locations using decimal degree coordinates, developed with the help of Hal Baker. Decimal degree coordinates were easier to use in Missouri, where there are two UTM zones, which make the use of UTM coordinates somewhat more difficult for statewide maps. I added some decimal degree coordinates to the data set from the Missouri Speleological Survey, Missouri Department of Conservation cave database, and the Heritage Database.

The Cave Focus Areas derived for this study do not pinpoint caves, but are polygons typically two to five miles in diameter, including one or more important caves or springs. Once the polygon shapefiles were created in ESRI's ArcMap®, the Cave Focus Areas could be included in an overall GIS for wildlife planning without revealing specific cave locations. Researchers and conservationists may obtain individual cave locations from the Heritage Database or the Missouri Speleological Survey on a need-to-know basis, with written justification.

I ranked caves for biodiversity, and I used the biodiversity index as an attribute in ArcMap to examine the geographic distribution of important biocaves. I created point files of caves with high biodiversity (Figure 2), priority 1 and 2 gray bat and Indiana bat caves (Figure 3), and cavefish sites



Fugure 2. High biodiversity caves in Missouri. The top ten biocaves are labeled, including Berome Moore and Tom Moore caves in the Moore Cave System.

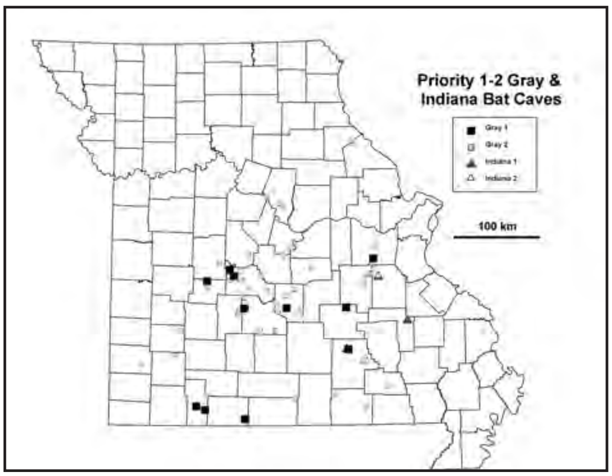


Figure 3. High priority gray bat and Indiana bat caves in Missouri. Most of the caves shown are gray bat maternity roosts, but some are hibernacula for one or both species.

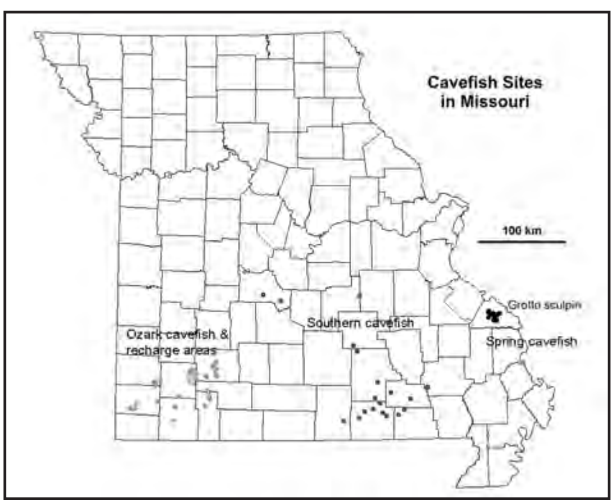


Figure 4. Cavefish sites in Missouri.

(Figure 4), with attributes for higher values.

The final step in delineating Cave Focus Areas was to create data layers in ArcMap of the above elements. I then manually drew polygon shapefiles around clusters of important caves and magnitude 1 karst springs. The latter springs often contain important groundwater species and represent hydrological connections over long distances, up to 65 kilometers in the case of Big Spring, Carter County, which flows about 12 m^3/sec (276 million gallons per day), with a peak flow of 37 m^3/sec (840 million gallons per day, Figure 5).

Results

The resulting 97 Cave Focus Areas are represented in Figure 6. The smallest areas represent single caves or springs, the largest represents the Perryville Karst and adjacent areas, about 15 x 65 kilometers in extent with roughly 700 caves. Overall, at least 350 biocaves and springs were included. More than 1,000 caves could be included if all areas were implemented.

Missouri Department of Conservation held a series of planning meetings in which many biologists pooled their knowledge and mapped potential Conservation Opportunity Areas. I contributed the Cave Focus Areas to that process. Many of the 33 identified Conservation Opportunity Areas in Missouri incorporate Cave Focus Areas. At least 12 of the 18 areas in the Ozark Highlands Ecoregion contain caves and karst: Bonne Femme Karst, Bryant Creek, Current River Hills, Eleven Point Hills, Manitou Bluffs, Middle Meramec, North Fork, Roaring River, Spring River, Tumbling Creek Cave Ecosystem, Upper Gasconade River Hills, and White River Glades and Woodlands.

Discussion

In Missouri, caves and karst have been mainstreamed into long-term wildlife conservation planning. The Missouri Comprehensive Wildlife Conservation Strategy will have multiple funding sources, including SWG (State Wildlife Grants through the U.S. Fish & Wildlife Service), LIP (Landowner Incentive Program), cost-sharing, partner money and others. Since 2001, the Missouri Department of Conservation has received a total of about $7 million in federal reimburse-

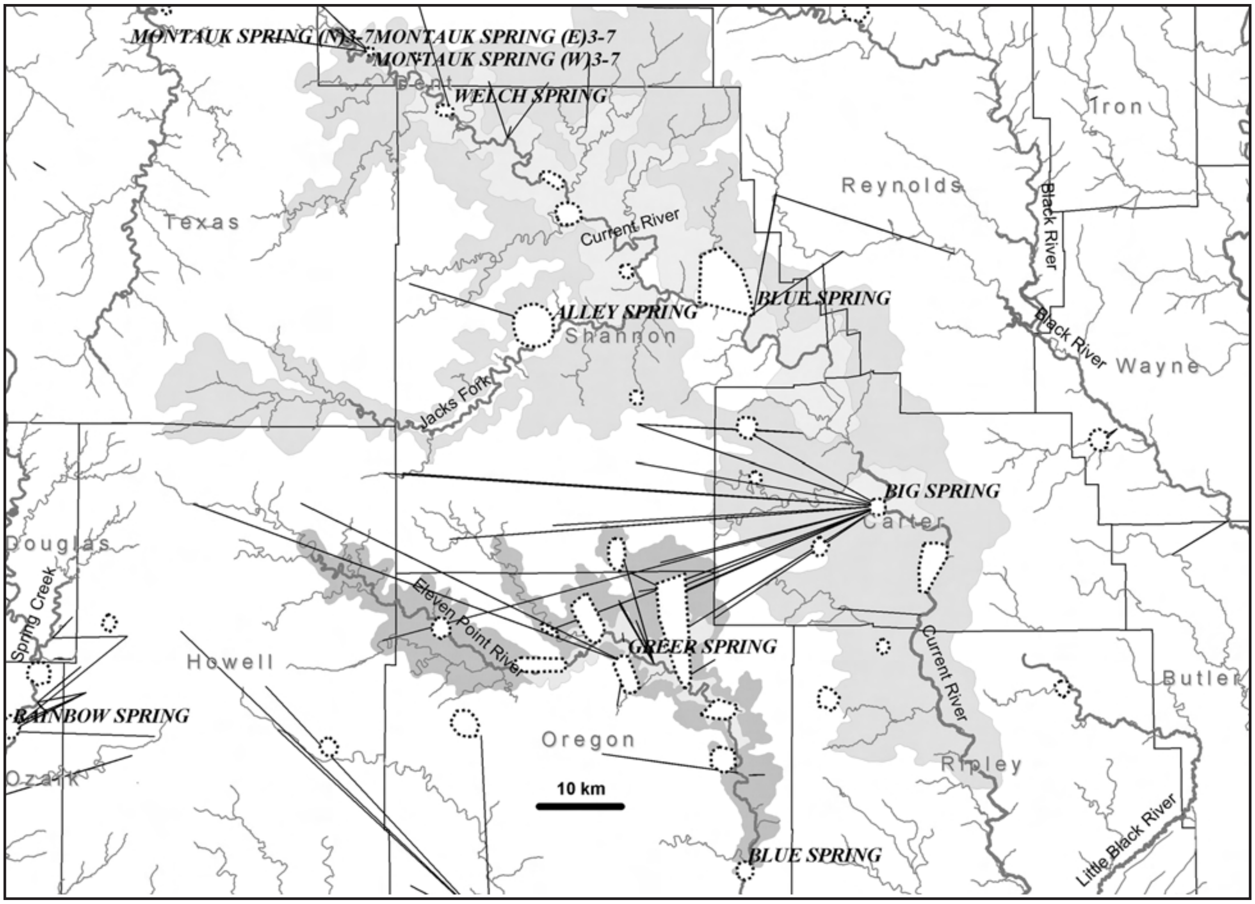


Figure 5. The Missouri Cave Focus Areas include magnitude 1 springs, such as this part of southeastern Missouri. Dye traces are shown as thin lines and cave focus areas as dotted outlines. Much of the flow of the Eleven Point River is pirated underground to Big Spring and the Current River.

ments, matched by a similar amount from the state and partners. Some of the funding has gone to caves and karst, mainly for gating important caves and assisting private cave owners. For the future, caves and karst will receive increased funding for cave protection, dye-tracing studies, bioinventory and census work, planning, land remediation, and landowner assistance.

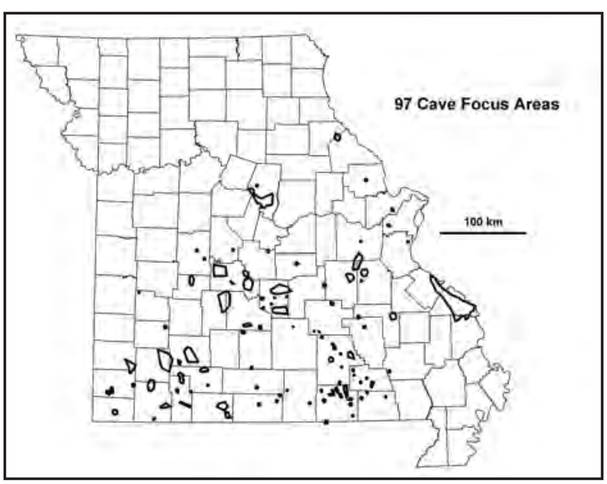


Figure 6. The 97 Missouri Cave Focus Areas.

Acknowledgments

I am grateful to my Cave Life Database partners for the use of their published and unpublished data: Michael R. Sutton, David C. Ashley, Mike Slay, Steve Samoray, Jim Kaufmann, Lawrence Ireland, and Scott House. Our combined efforts have allowed us to prioritize cave protection efforts through the Missouri Cave Protection Working Group. I thank the Missouri Speleological Survey for the temporary loan of cave location data, and the Missouri Natural Heritage Database staff for their assistance and many other cave location data. I am especially grateful to Hal Baker, Missouri Caves & Karst Conservancy, for

his assistance in developing a GIS-friendly table of biocaves for this study.

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CAVE MANAGEMENT GUIDELINES FOR WESTERN MOUNTAIN NATIONAL PARKS OF CANADA

September 2005

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Abstract

At least 12 of 41 national parks in Canada have caves. A group of six parks in western Canada are preparing to adopt cave management guidelines using a three-tier classification system to manage access. Class 1 caves are access by application — highest resource value, not for recreation, each visit must add knowledge or give net benefit to the cave. Class 2 caves are access by permit — recreational use allowed, some management concerns, education/orientation possible during permit process. Class 3 caves have unrestricted public access — few or no management concerns, no permit required.

In order to determine which class each known cave sits in, three sets of factors are considered; (a) cave resources, (b) surface resources, and (c) accident and rescue potential.

Cave exploration in the western Canadian mountain national parks began in the 1960s. This current access policy has been influenced by the remote rugged nature of the landscape and the need to work with speleological groups to explore and document park features. A change in park staff awareness of the resource has contributed greater exchange of information and opportunities for cavers to gain access and the park to know more about its resources.

1.0 Setting

These guidelines pertain to six national parks located in the western Cordillera of Canada, in the provinces of Alberta and British Columbia. Four of the parks, Jasper, Banff, Yoho, and Kootenay form a contiguous block in the Rocky Mountains between latitudes 53 degrees 30 minutes north and 50 degrees 30 minutes north. The remaining two Parks, Glacier and Mount Revelstoke, are located further west in the Selkirk Mountains. In general, these parks range in altitude above sea level from 1,000 meters to just below 4,000 meters. Depending upon elevation and aspect, the terrain can be covered by snow from late September to June. Glaciers and icefields are present in all parks. All parks are predominately covered by conifer forests. The treeline is approximately 2,100 meters.

2.0 Background

Although the majority of the combined area of these parks (24,600 square kilometres) features carbonate bedrock, approximately only 100 caves have been discovered. Prior to the 1960s when systemic searching for caves began, very few caves were reported or well known. Interest in the national park system of Canada began (1885) with the European discovery of a cave associated with a hot spring in what is now Banff National Park. Presently the cave is managed as a national historic site, Cave and Basin. The other notable except was Nakimu Caves in Glacier National Park. Discovered in 1902, the caves were soon developed into the only true show cave in Canada's national park system. In 1935 the show cave was closed, mainly due to dwindling tourist interest as the result of changed surface access and infrastructure.

Since the late 1960s, the search for and exploration of caves in this group of six national parks has been primary conducted by McMaster University karst research group and more recently the Alberta Speleological Society. The most significant cave explored is Castleguard Cave in northern Banff National Park. Surveyed to 20 kilometers, Castleguard is the longest cave in Canada and the only known cave under an icefield with numerous passages choked with glacial ice.

In 1975, an Order in Council was passed that made the first specific mention of caves with regard to regulation. Section 34A read; *"Except with the permission of the Superintendent, no person shall enter any cave in a National Park"* The 1978 revision of the National Parks Act modified the regulation to its present wording (see 7.2 legislation).

Rick Kunelius, Park Warden from Banff National Park, authored a report about caving in the late 1980s, *Caving - No. 15, A Background Paper for the Four Mountain Parks Planning Program*. Kunelius wrote a frank report that highlighted the unsatisfactory situation, for both cavers and park resource managers, that existed at the time. He suggested a three-tier classification system with some similarities to this present proposal.

At the same time, interest in national park caves had waned after most easily accessible and obvious caves had been explored and surveyed. Other areas of the Canadian Rocky Mountains, outside national parks, with much higher density of caves, focused the attention of the Alberta Speleological Society. Still, there has been an on-going interest in access to Castleguard Cave. In 2004 the publishing of a cave guidebook that included many of the caves found in the six national parks raised awareness but so far not an interest in park caves.

3.0 Current Situation

The National Park General Regulations; section 8, reads, *Except where it is indicated by a notice posted by the superintendent at the entrance to a cave that entry therein is permitted, no person shall enter any cave in a Park without the permission, in writing, of the superintendent.* Cavers have lobbied for the revocation of the regulation based on the argument that their activity has been unfairly singled out and they wish to be treated the same as hikers or climbers.

Realistically, revoking section 8 will not happen for a number of reasons. Nationally, there are management issues and concerns beyond the scope of recreational caving. Some coastal parks have native burial sites in sea caves, others have long ago closed mines (the national park definition of cave: *any subterranean cavern or area, either natural or man-made*), some have bat hibernaculums and most parks with solution caves have some fragile speleothems or other significant features worth protection. The national park mandate, as stated in its act, reads that parks; *shall be maintained and made use of so as to leave them unimpaired for the enjoyment of future generations.*

Therefore, regulations such as section 8 will remain and be used as required. However, there are ways of administering the regulation so as to restrict access only for those caves where there are resource protection and or public safety concerns. Because of the wide range of resource management and public safety concerns across a national system of 41 parks, the proposed access management guidelines presented here apply only to the following western mountain national parks: Jasper, Banff, Kootenay, Yoho, Glacier, and Mount Revelstoke. This is a group of parks with a similar cave exploration history and surface landscape. The access guidelines presented here were circulated to executive members of the Alberta Speleological Society and the British Columbia Speleological Federation, Canadian cave/karst consultants and a U.S. National Park Service ecologist several years ago. Their feedback was considered and incorporated, where possible, into the draft presented here.

4.0 Introduction

The task of developing cave management

guidelines was first directed towards the caves of Jasper National Park then expanded to include the neighboring National Parks of Banff, Kootenay, Yoho, Glacier, and Mount Revelstoke. Although not prominent or numerous, caves are special natural resources that are worthy of specific management guidelines.

5.0 Park Management Plan Background

Park management plans, both current and the recent past, (1988 era) of the four mountain parks block (Jasper, Banff, Yoho, and Kootenay) and Glacier/Revelstoke National Parks were reviewed for direct reference to cave management. These highlights are presented in Appendix I. These plans recognize caving as a legitimate activity for the purposes of exploration and recreation. The 1988 Jasper Park Management Plan suggested the classification of formations as a means of managing resource protection and public safety concerns. Possibly what was meant was the classification of caves based upon the fragility of their resources and the physical difficulties for people to move through them?

6.0 Current Knowledge of Resource

In 1992 Jon Rollins completed a very useful inventory of known caves in the southern Canadian Rockies as part of his masters degree of Environmental Design from the University of Calgary, *Management Considerations for Caves and Related Karst Features in the Southern Canadian Rockies.* The masters degree project received financial assistance from Parks Canada. In the 13 years since his original inventory, other caves within National Park boundaries have been located or documented. Rollins' inventory was a combination of site visits, literature review, and interviews. The level of detail he provided in the inventory varies, but needs to be expanded to better meet the park's requirements.

The current level of exploration of new caves and documentation of unreported ones appears to be averaging out to about one or slightly less per year in Jasper National Park. The discoveries are being made by local cavers and park staff (who are becoming more aware of the significance of caves). With improved relations between cavers and park staff, it is now possible for an information exchange about new resources to take place. In the past this dialogue would not have been possible due to perceived and actual adversarial positions.

The size (length and depth) of known caves in the mountain national parks, with the exception of Castleguard and Nakimu Caves, are all relatively small compared to other areas of the Canadian Rockies or Vancouver Island. However, national park caves do include a number of significant features or resources such as bat hibernaculums, ice caves, sulphuric acid formed caves, bone beds, and many types of formations (draperies, evaporites, flowstone, helictites, moonmilk, stalactites, stalagmites). Many of the known caves in national parks are situated in remote backcountry locations, some several hours to multiple days travel from the road.

7.0 Cave Management is People Management

Under the present mandates of National Parks in Canada, cave management is about managing people who enter caves or whose actions outside may effect caves or neighbouring surface resources. The principal cave management goal for National Parks will be conservative use of cave resources balancing protection and conservation against understanding, appreciation, and use.

7.1 Purposes of Legitimate Cave Visitation

Public
- Exploration in conjunction with detailed survey, map production, and resource inventory, as well as a written report of new knowledge gained from the exploration.
- Research related to resources found within
- Recreation, appreciation, and enjoyment of the cave resource in a non-consumptive way

Park staff
- Orientation of known caves for the purpose of understanding the significance of resources present
- Exploration and survey
- Resource inventory
- Monitoring the impacts of visitation and research
- Restoration or rehabilitation of man

caused impacts
- Assessing and mitigating safety issues
- Prepare interpretive material
- Lead public interpretive tours

7.2 Cave Management Strategies

To implement the cave management goal, a combination of strategies will be used, these include:

Isolation - Keep the caves isolated (remote) by restricting the use of mechanized transportation for access, route trails away from caves where possible, and restrict new developments away from caves.

Information Management - Do not publicize specific cave locations or access trails. This should be interpreted as a philosophy of not actively disseminating information but does not preclude off-site interpretation.

Diversion - Redirect potential users to less sensitive caves either inside National Parks or to other caves in neighbouring provinces.

Education - Educate the general public about the value of caves and karst. Educate cave users about cave conservation ethics, information sources, and speleological organizations.

Legislation - Use the National Park Act and Regulations to control access and user actions when necessary. Examples include the General Regulations; section 8, *Except where it is indicated by a notice posted by the superintendent at the entrance to a cave that entry therein is permitted, no person shall enter any cave in a Park without the permission, in writing, of the superintendent.* section 10, *No person shall remove, deface, damage or destroy any flora or natural objects in a Park except in accordance with a permit issued under subsection 11(1) or 12(1).*

Related to wildlife protection, use the Wildlife Regulations; section 4(1) *Except as otherwise provided in these Regulations, no person shall (a) hunt, disturb, hold in captivity or destroy any wildlife within, or remove any wildlife from, a park; (e) disturb or destroy a nest lair, den or beaver house or dam in a park;*

Resource Inventory - Keep up-to-date information on karst and cave resources by sharing information with speleological organizations and park staff.

Ecosystem Approach - Ensure the hydro-geological catchment of a karst or cave resource is understood before a new development is considered in the area.

Monitoring and Evaluation - Acquire baseline data and periodically monitor the short and long term effects of human impact on cave resources is essential for evaluating the success or failure of these guidelines.

8.0 Cave Classification

The purpose of a cave classification system is to assist with management decisions related to the protection of natural cave environments and providing public access. The classification system must be understandable to both resource managers and the public. A three-tier classification is proposed for western mountain National Parks. The factors to be considered will include: (A) the cave resources, (B) the surface resources, (C) accident and rescue implications

8.1 Cave Resources

The resources contained in a cave will vary widely from one cave to another. Consideration shall be given to:

- uniqueness of speleothems, secondary deposits or other notable resources
- fragility of speleothems, secondary deposits or other notable resources
- abundance of speleothems, secondary deposits or other notable resources
- susceptibility of cave fauna to disturbance
- potential to contain scientific value

8.2 Surface Resources

The surface resources surrounding a cave, including its entrance, may be impacted by visitation. The considerations for these resources shall be:

- susceptibility of flora or fauna to disturbance
- uniqueness of flora or fauna
- potential for users to attract more interest to a cave by creating a trail or obvious track to a cave

8.3 Accident and Rescue Implications

The consequences of an accident in a cave are:

negative effects on cave resources, rescue costs to tax payers, and negative media exposure. The considerations regarding accidents and rescues shall be:

- potential in-cave hazards
- seriousness and difficulty to complete an in-cave rescue
- access logistics to reach the cave entrance
- potential damage to cave resources by carrying out a rescue

Using these consideration factors, a three-tier cave management classification will be:

8.4 Class 1—Access by Application

Caves of highest resource value, significant disturbance potential to surface resources, serious consequences of an accident, and/or a combination of these factors. These caves are not for recreational purposes; visits must add to the knowledge base and or give net benefit to the cave. These caves will require detailed management actions and or screening of users by an application process. Monitoring of user activity and resource impairment will be required. Education and orientation of users is possible by direct contact during application process. Legitimate visitation purposes could include new exploration or survey, map production, resource inventory, rehabilitation or restoration, or bonafide scientific research. Applicants should typically submit a written proposal. Approval may require one to three months depending upon the complexity of the access proposal.

Few caves will have this designation, a well known example is Castleguard Cave.

8.5 Class 2—Access by Permit

Caves having some management concerns regarding their internal resources, surfaces resources, or accident potential. These caves will require a straight-forward access permit, for example a special/restricted activity permit. Recreational use is allowed. Monitoring of user activity and resource impairment may be required. Education and orientation of users is possible by direct contact during permit process. Approval may require one day to a week depending upon season and staff workload.

Most of the caves will have this designation. Seasonal restrictions for bat hibernaculums will elevate winter access to Class 1.

8.6 Class 3—Unrestricted Public Access

Caves having few or no management concerns regarding their resources, surfaces resources or accident potential. These caves will be open to the public without a permit. Monitoring will carried out on an infrequent basis. To work with the intent of General Regulations, section 8 *(Except where it is indicated by a notice posted by the superintendent at the entrance to a cave that entry therein is permitted, no person shall enter any cave in a Park without the permission, in writing, of the superintendent.)*, it is proposed that a public notice from the Superintendent would list the caves in this class and give a blanket permit to the public for access. The notice would be kept at the park administration, trail, and warden offices. This list would not be advertised or marketed. The list would be made available upon request by the public.

Some caves, typically those which are small, with few speleothems and minimal safety/rescue concerns will be open to everyone.

8.7 Determination of Cave Management Classification

Each park cave or group of caves needs to be assessed regarding its in-cave resources, surface resources, and rescue implications. If there is little or no information about a particular cave then its default classification shall be Class 2 until there is enough known about it to use the proposed rating scheme.

Initially, in an earlier draft, a numerical rating system was developed to objectively score each cave in order that consistent and defendable application of the classification system be made. Of all the comments received during first round of consultation, many respondents highlighted the difficulty of truly creating an objective rating scheme by trying to put numbers to difficult-to-quantify resources. Instead, the previously listed Factors To Consider For Determining Cave Access Classification will be used as a checklist when determining which access class a cave will be placed in.

If cavers wish to carry out a reconnaissance trip to check an area for new prospects and enter discovered finds, this will be possible. Unless there are access restrictions for all park users (fire hazard, bear closure, avalanche control, trail or campground quotas, bivi restrictions, and the like), access can be provided similar to the conditions of Class 2 caves. The important message is communication. In the past there have been misunderstandings and poor communication between cavers and Parks Canada. This opportunity to comment on these guidelines is hopefully an example of a positive change. User input to this proposed cave access policy change is desired.

The classification of a cave can change with new information available about the cave resources, user activity or surface resources. In a large cave there is the possibility that different parts of it can be designated to different classes.

9.0 User Activities

Once access has been secured to any cave, important user ethics that need to be followed to ensure sustainable use of the cave. The Leave No Trace (www.lnt.org) organization has recently (1998) produced a booklet in their skills and ethics series devoted to caving. This booklet summarizes many common concerns cave managers will want users to be aware of. Until there is a Canadian equivalent, this should be the standard handout to cavers upon first contact. There is something to learn or refresh everyone's memory in the booklet.

Cautionary information about cave specific resources that require or justify special mention should be attached to the permit. The level of detail and important conservation messages stressed to the user will be determined by park and the resources at risk.

Author Biographical Sketch

Greg Horne is a Park Warden in Jasper National Park, Alberta, Canada. His primary job responsibilities are related to backcountry management and patrol. For the past decade he has been involved with cave management issues primarily in Jasper National Park and Castleguard Cave in neighbouring Banff National Park. As well, he has drafted a cave classification and management system for six mountain parks of western Canada. He has been Parks Canada's representative to liaison with the Alberta Speleological Society. He has advised Nahanni National Park Reserve (Northwest Territories, Canada) regarding potential park expansion into the Nahanni North Karst area. Personal interest in cave exploration has taken him to Australia, Bolivia, and Mexico.

APPENDIX I

Jasper

The Jasper National Park Management Plan of November 1988 gave public direction as to how caving will be treated. Under the section titled Recreational Activities caving is discussed as follows:

Arrangements for authorization to enter caves, protection of significant resource features, and public safety will be assured through cooperative efforts with recognized speleological organizations. The park service will cooperate with recognized speleological organizations to complete a preliminary inventory and classification of cave formations. The Canadian Parks Service will then prepare management guidelines which will identify the requirements for the protection of specific cave formations.

Discussion:

Caving is not a particularly popular activity. There are few known accessible cave formations in Jasper. The cooperation of recognized speleological organizations is the only practical manner in which knowledge of these karst features can be obtained. At the same time, restrictions and controls are necessary because of the fragility of many karst features and to ensure that public safety requirements are met. These can be established only on completion of a proper inventory and classification of specific cave formations.

The proposed arrangements will achieve the resource protection requirements by controlling access to caves once they are known, while providing the park superintendent with discretion to permit responsible organizations to enter specific caves. The cooperative approach taken in the preliminary exploration of the Snaring Karst System is an example of how the Parks Service and speleological organizations can work together to better understand and manage the park's resources.

The Jasper National Park Management Plan Concept (January 29, 1999) gives brief mention of cave management in section 5.0 A Place for People - Visitor Services and Facilities:

Review the park cave management policy to better match management action with the necessary level of resource protection.

The Jasper National Park Management Plan (May 2000) expands on the previous statement in section 5.0 A Place for People, Effective Human Use Management 5.6.3.17: *Review the park's cave management policy to ensure proper resource protection. In some cases current restrictions are not necessary for resource protection or public safety. As a result, the requirement for permits is often ignored. A new policy would only require permits where there are resource or public safety concerns.*

This statement hints of the cave classification system later proposed in this document.

Banff

The November 1988 Banff National Park Management Plan, Recreational Activities 4.3.T uses the same introduction as the 1988 Jasper plan regarding caving. The discussion is slightly different and reads:

Banff contains several well-known cave systems in Mount Castleguard and Sulphur Mountain. Restrictions and controls are necessary because of the fragility of many karst features and to ensure public safety requirements are met. The proposed arrangements will achieve the resource protection requirements by controlling access to known caves.

There are also a number of caves in the park which have not been documented. The cooperation of recognized speleological organizations is the only practical manner in which knowledge about these features can be obtained. These organizations have not always found Parks Service officials to be cooperative in authorizing entry into caves. The proposed arrangements would provide the park superintendent with the discretion to permit responsible organizations to enter caves.

The Banff National Park Management Plan (April 1997) makes two direct references to caves. In the section A Place for Nature, 3.7 Geology and Landforms, 3.7.2 key action states: *Provide special protection measures for internationally and nationally significant features and landforms such as the Castleguard Caves, the Middle Springs hot springs, and important fossil beds.*

The second reference is in Park Zoning, 10.2 Zone 1 - Special Preservation, Castleguard Cave System and Meadows Zone 1 Area: *The Castleguard Cave System is a karst system that is internationally recognized fir its physical development,* *diversity of features, and rare and unique fauna. At more than 16 km, it is the longest cave in Canada and the second deepest cave in the country. The entire Castleguard Cave System contains a notable variety of special features including stalagmites and stalactites, precipitates of gypsum, hydromagnesite and rare cave minerals. The Castleguard area not only contains significant surficial karst features but is also an outstanding example of pristine alpine vegetation.*

Castleguard is actually now about 20 kilometers surveyed length but has dropped in depth ranking to about 5th or 6th deepest.

Yoho

The November 1988 Yoho National Park Management Plan uses the same introduction in 4.3 Recreational Activities for caving as Jasper and Banff. The discussion reads differently:

There few known cave formations in Yoho and caving is not a popular activity. The number of cavers operating in the mountain parks is low, and Yoho does not receive a large proportion of this use. The activity is therefore of minor management concern. Reports from cavers help the park to discover and understand Yoho's underground resources.

Use will be monitored through permits and caving reports, in cooperation with recognized speleological organizations. It is not expected that caving will increase to the point where additional management actions are required.

In the current draft Yoho National Park Management Plan brief mention is made to caves under 3.0 A Place for Nature, 3.8.3.1 key actions: *Provide special protection for the Burgess Shale fossil sites and the Ice River Igneous Complex and caves.* The next key action, 2, could be interpreted to relate to caves and speleological organizations as well: *With other interested parties, assess the park's understanding of its geological resources; determine research priorities.*

Kootenay

The November 1988 Kootenay National Park Management Plan uses the same introduction in 4.3 Recreational Activities for caving as Jasper, Banff and Yoho. The discussion reads differently:

There are no known caves in the park, although no systematic investigations have been undertaken. The cooperation of recognized speleological organizations is the only practical manner in which knowledge about these features can be obtained. At the same time, restrictions and controls are necessary because of the fragility of many karst features and to ensure public safety requirements are met. These can established only on completion of a proper inventory and classification of specific caves.

The proposed arrangements will achieve the resource protection requirements by controlling access to caves once they become known, while providing the park superintendent with the discretion to permit responsible organizations to enter specific caves.

In the current draft Kootenay National Park Management Plan, using the exact same wording as the Yoho draft, brief mention is made to caves under 3.0 A Place for Nature, 3.8.3.1 key actions: *Provide special protection for the Burgess Shale fossil sites and the Ice River Igneous Complex and caves.* The next key action, 2, could be interpreted to relate to caves and speleological organizations as well: *With other interested parties, assess the park's understanding of its geological resources; determine research priorities.* This is assumed to be an editorial slip regarding citing Yoho specific geological features.

As a point of interest, there are at least 11 known caves in Kootenay, one known of as early as 1977 and numerous as of 1987 and 1988. Several are described as having impressive formations, pits and active stream passages. The first known find, in a Canadian cave, of the mineral Attapulgite is in a Kootenay Cave.

Glacier and Revelstoke

The 1995 Mount Revelstoke and Glacier National Parks Park Management Plan speaks about caves in section 5.3, Land Use Zoning Plan Glacier National Park:

Zone I - Special Preservation

The Nakimu Caves System was identified as a site encompassing features of exceptional regional significance in the 1984 Regional Analysis of Natural Region Four. The Nakimu Caves are one of the most extensive cave systems known in British Columbia, and at over five km of passages, are second only to the Castleguard Caves in Alberta. Located in the Cougar Valley, the system consists of three small upstream caves and a main cave. Visible at the surface are sink-

holes, springs, a dry valley and an unroofed cavern. Features found inside the caves include waterfalls, plunge pools, stalactite grottoes, moonmilk and seasonal and permanent ice deposits. Surface vegetation near the caves is also of special interest due to the presence of calcicole plant species. Calcicoles are rare in the Selkirk Mountains due to the limited occurrence of limestone parent material and calcareous soils.

Nakimu Caves are designated a Zone I area due to their significant karst features, and represent less than 1% of the park.

Several other potential Zone I areas exist but require further investigation. For example, the 1984 Regional analysis of Natural Region Four identified the Mount Tupper cave system as a potentially exceptional feature. The cave system begins with two sinkholes, one of which carries meltwater from the East Tupper Glacier. Subterranean passages at the upper end of the system are narrow and silted. Glacier water disappears here to re-emerge 500 metres below.

The next mention about caves is under section 7.2, The Park Visitor Groups - Adventure Recreationists: *Adventure recreationists are those visitors who participate in adventure activities that enable them to challenge the natural environment on its own terms in order to appreciate, understand and enjoy the parks wilderness character. Important elements of the experience sought are opportunities for persona challenge, risk, adventure, accomplishment, solitude and skill development in a rugged and primitive setting. The range of activities these individuals undertake include ski touring, mountaineering, climbing, caving,, backcountry hiking, kayaking rafting, canoeing and horseback riding. Minimal basic park facilities are required by this group.*

Section 7.3, Visitor Experience Opportunities, states: *The visitor experiences that are in keeping with the parks market niche of a "wilderness experience" and will be provided within RNP/GNP are: - caving* [plus ten other traditional activities].

STRATEGY FOR MANAGING ALPHA RADIATION IN SHOW CAVES TO PROTECT CAVES, CAVE EMPLOYEES, AND CAVE BUSINESSES

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Abstract

Alpha radiation due to radon and thoron daughters is routinely encountered in show caves and has been the subject of several papers at previous cave management symposiums. Alpha radiation has been correlated with an increased risk of lung cancer. This correlation is largely based upon studies of lung cancer in career miners exposed to alpha radiation and other carcinogens and lung irritants. However, the general regulatory model is the "linear, no threshold" model, which means that any radiation increases the risk of subsequent lung cancer and that it is the lifetime dose, rather than the rate, that correlates with the risk. This approach was affirmed in June 2005 by a National Academy of Sciences panel.

The authors of this paper and their respective organizations recognized that a management strategy was needed to provide reasonable protection for show-cave employees, show caves, and show-cave businesses. To address the issue an Alliance Agreement was developed between the Occupational Safety and Health Administration (OSHA) and the Ozark Underground Laboratory. The National Caves Association funded the Ozark Underground Laboratory's participation. This paper summarizes results to date from the project, discusses the emerging cave radiation management strategy that we anticipate will be largely or completely implemented by the National Caves Association, and demonstrates the benefits of Alliance Agreements.

Introduction

One of the first times the cave radiation issue came to the attention of American cave managers was at the first Cave Management Symposium, which was held in Albuquerque, New Mexico (Van Cleave, 1976). The second Cave Management Symposium produced three papers on the issue; these were by Yarborough (1977); Ahlstrand (1977) and Aley (1977). Yarborough (1977) provided some basic information about alpha radiation in caves and then summarized radon daughter concentrations in National Park Service (National Park Service) caves. He also outlined a regulatory strategy for National Park Service show caves that was patterned after mining standards administered by the Mining Enforcement and Safety Administration (MSHA). Ahlstrand (1977) reported upon rather detailed and wide-ranging research investigations in Carlsbad Cavers. Aley (1977) was concerned that poorly conceived management efforts could damage cave resources and that regulatory strategies appropriate for mines were not well suited to show caves. Since the time of the Second Cave Management Symposium, little has changed relative to the management of the issue. The National Park Service has followed the approach outlined by Yarborough (1977) and this has resulted in about 30 years of alpha radiation monitoring at the larger National Park Service show caves and record keeping to ensure that no employee exceeds the annual alpha radiation dose permissible in the mining industry. Some state-operated show caves have adopted some similar strategies. In 1978 the National Caves Association adopted standards which, among other things, specified that cave employees working at National Caves Association-member show caves were not to exceed 700 hours of work underground per year unless the cave was monitored for alpha radiation and that monitoring demonstrated that they would not exceed the annual alpha radiation dose permissible in the mining industry.

What is alpha radiation and why is it of concern?

Uranium and thorium are radioactive elements that are widely, but unevenly, distributed in bedrock and soils. Elevated concentrations are sometimes (but not routinely) encountered in limestones, dolomites, and shales. No geologic setting can be assumed to be free of these elements.

One of the radioactive decay products of Uranium-238 is radium, which in turn decays to radon-222 (which we will simply call radon in this paper). Radon is a colorless and odorless gas with a half-life of 3.8 days. It has four radioactive decay products (called daughters) with half-lives ranging from 22 years to a fraction of a second.

The atomic decay of thorium similarly produces thoron gas, and the decay of that gas produces two radioactive decay products (again, called daughters). Thoron daughter concentrations in cave air are routinely much lower than are the concentrations of radon daughters. Total alpha radiation in a cave is the sum of radon daughter concentrations and thoron daughter concentrations. Based upon monitoring results from 71 show caves in the United States radon daughter concentrations average about 95% of total alpha radiation. In a few caves radon daughter concentrations can be as low as 63% of total alpha radiation, but in these cases total alpha radiation is typically relatively low.

During the radioactive decay of radon and thoron daughters they emit alpha particles. The particles are large and, as a result have little or no ability to penetrate most materials (including human skin). However, if alpha particles are inhaled they may reach cells in the lungs that are sensitive to damage from the ionizing charge of the particles. This damage may increase the risk of developing lung cancer at some time in the future.

Smoking is the leading cause of lung cancer in the United States. The lung cancer risk for smokers is about ten times greater than the risk for non-smokers (Cohen, 2000). Radon combined with cigarette smoking appears to act synergistically. The risk of both factors in combination is greater than the risk associated with the sum of the factors. The extent of the synergistic effect is unclear since the basic studies used data from underground miners in poorly ventilated, high-alpha-radiation environments where non-smokers were under-represented and where non-smokers were exposed to appreciable second-hand cigarette smoke and to industrial smoke (diesel fumes and fumes from explosives).

Cole (1993) provides an excellent summary of the alpha radiation issue and its associated politics. Papers by Yarborough (1977) and Aley (2000) provide readable summaries of alpha radiation conditions in caves. It is beyond the scope of this paper to consider the validity of the correlation between exposures to alpha radiation and an increased risk of ultimately developing lung cancer.

Alpha radiation is regulated in the mining industry and maintaining or creating low radon concentrations in homes is strongly recommended by various agencies including the U.S. Environmental Protection Agency. Aley (2002) suggested that arguing that a causative link between alpha radiation as encountered in caves where cigarette smoke is absent and an increased risk of subsequent lung cancers is not going to be politically successful. In fact, he compared the likely success of such an argument to the likely success of arguing that you cannot hijack an airplane with a pair of nail clippers and thus you should be allowed to take them on through the airport security check point at which you have been detained. The political reality, and presumably also the technical reality, is that alpha radiation as encountered by employees in show caves must be approached as a valid employee health issue and addressed in a credible manner by management strategies.

There are several basic regulatory presumptions about alpha radiation. The first is that the risk is dependent upon the total amount of alpha radiation one receives (the dose) rather than the rate at which it is received. The second is that there is no safe threshold value below which there is no risk. The third is that the relationship between the total alpha radiation exposure and the risk is linear. The second and third presumptions were affirmed in June 2005 by a National Academy of Sciences panel.

Monitoring Radon and Alpha Radiation

Radon is a gas and is commonly the parameter measured in the basements of homes in units of picoCuries per Liter of air. In contrast, alpha radiation derived from radon and thoron daughters is measured in Working Levels (WL). One WL is defined as any combination of radon and/or thoron daughters in one liter of air that will result in the ultimate emission of 1.3 x 105 MeV of potential alpha energy. Cumulative exposure is measured in working level months (WLM). This is the exposure accumulated from breathing air at one WL concentration for 173 hours or other combination of time and radiation concentration.

There is no constant coefficient ratio for converting picoCuries per Liter to Working Levels since the ratio of the two is a function of the extent to which the radon daughter products are in equilibrium with the radon gas. In "real-world" conditions the equilibrium constant varies from about 0.1 to 1.0.

- The equilibrium constant in houses is typically about 0.5; this means that 200 picoCuries per Liter of radon equals 1 WL of alpha radiation.
- In well-ventilated mines it is typically about 0.3; this means that 300 pico Curies per Liter of radon equals 1 WL of alpha radiation.
- In unventilated mines it is about 1.0 since the gas and its decay products are at or near equilibrium (Aley, 2000); this means that 100 picoCuries per Liter of radon equals 1 WL of alpha radiation. The time required for radon and alpha radiation to reach equilibrium is about 3 hours (Aley, 2000).
- Except for some notable exceptions, in most show caves the equilibrium constant probably ranges from 0.5 to 1.0 and is commonly near the upper limit of this range, particularly in caves with higher alpha radiation concentrations. If the constant is near the upper limit of the range it is similar to that characterizing unventilated mines.

The standard method for monitoring caves (or for that matter, mines) for alpha radiation is by using a calibrated air sampling pump and pulling a known volume of air over a five-minute period through a filter that will trap the alpha particles. The filter is subsequently placed in equipment that will count the alpha emissions over a standard counting period. Equations are then used to calculate the alpha radiation in WL; the equations include time corrections to adjust for half-life decays. The filter is first counted for radon daughters 40 to 90 minutes after the air sample is collected, and then counted for thoron daughters 5 to 17 hours after sampling.

Alliance Agreement

In 2002 the National Caves Association contracted with the Ozark Underground Laboratory for a three year project (now expanded to four years) on alpha radiation in National Caves Association-member caves. The number of National Caves Association-member caves varies slightly from year to year; in 2005 National Caves Association had 92 members including ten caves owned by state or county governments; five federally owned and operated caves, and one cave in Bermuda. In a few cases there are two or more caves at a particular member site. We estimate that 85 to 90% of all show-cave visits in the United States are to National Caves Association-member caves. The National Caves Association is the logical representative of the show-cave industry in the United States.

The Ozark Underground Laboratory established an Alliance Agreement with OSHA. While the agreement is between Ozark Underground Laboratory and OSHA, it is for the benefit of the National Caves Association. Alliance Agreements are formal agreements between OSHA and another entity (such as Ozark Underground Laboratory or National Caves Association) to work cooperatively on a particular issue that has safety or health implications for employees. The authors of this paper, who individually represent the Ozark Underground Laboratory, OSHA, and National Caves Association, have found the Alliance Agreement strategy to be an excellent vehicle for assessing the issues and developing a management strategy that will simultaneously protect show-cave employees, show caves, and show-cave businesses.

Early in the Alliance Agreement OSHA personnel noted that most of their work was associated with man-made environments rather than natural environments such as caves. They further noted that, unlike buildings, modifying caves in an effort to protect workers was unlikely to be an appropriate strategy. Throughout the Alliance Agreement OSHA has recognized the need to maintain the natural conditions found in caves. The natural significance of the National Caves Association-member caves is illustrated by the fact that a number of them are primary features in state and federal parks. Of the 71 private and state show caves monitored to date:

- Ten are designated National Natural Landmarks and five more have been proposed, evaluated, and recommended for National Natural Landmark designation. Natural features in these caves have federal legal protection.
- Twelve of the caves have state significance designations such as state natural area or state landmarks.
- Four of the caves provide habitat for federally listed threatened or endangered species and three provide habitat for state listed species. Changes in the cave environment that degraded the suitability of the habitat for federally listed species would violate the Endangered Species Act.

In recognition of the significant natural features that caves are (and that they contain) the parties to the Alliance Agreement agreed early in the process that management strategies for alpha radiation should not include artificially ventilating caves except, perhaps, in a localized and unique circumstance. Caves are best protected if their natural microclimates are preserved or, if they have been altered by past actions, returned to conditions as near-natural as possible. The importance of not artificially ventilating a cave to lower alpha radiation concentrations is demonstrated by a very unfortunate example. A number of years ago the National Park Service Superintendent at Oregon Caves National Monument ordered that the three entrances to the cave not be covered with canvas or lumber during the winter so as to maximize convective airflow through the cave and thus keep alpha radiation concentrations very low. Such strong convective airflows through the cave were not natural, and the highest elevation entrance is a man-made tunnel. The elevational difference between the top and bottom entrances is over 300 feet, and the result of the National Park Service action was that cold winter air at temperatures less than freezing was rapidly drawn into the lower entrance where it froze and shattered hundreds of soda straw stalactites along the first few hundred feet of the lower passage.

The Americans with Disabilities Act (ADA) provides a good precedent for not degrading historical or natural features in order to comply with fundamental ADA requirements for equal access. Exceptions to ADA requirements have been made, and supported by the courts, if compliance with the standards would alter the quality of the building or feature to the point that it no longer maintains its significance. As a case in point, if upgrading the public restrooms in an historic building degrades the significance of the historic architecture, then it is not reasonable to damage the feature to meet ADA standards. The same holds true with caves and is the reason that most caves are not handicapped accessible. Extending this to the cave radiation issue, ventilating a cave to reduce alpha radiation concentrations is not reasonable if it would damage or degrade the cave or the experience of the cave tour. In most cases ventilating a cave would cause significant damage.

Alpha Radiation Monitoring

A crucial part of the Alliance Agreement program was to develop a general understanding of alpha radiation concentrations at National Caves Association-member show caves. The federally-operated show caves and three of the state-operated show caves did not contribute to funding the study and were not included in the study. Some of these government caves already have conducted alpha radiation monitoring. In addition, several of the state-operated caves that contributed to the study, plus some private caves, also had previous alpha radiation monitoring. As of September 1, 2005, a total of 71 caves in 19 states have been monitored for alpha radiation by the Ozark Underground Laboratory.

Papers by Yarborough (1977 and 1978) and Ahlstrand and Fry (1978) demonstrate that alpha radiation concentrations in caves vary diurnally as well as seasonally. To the scientist this suggests the necessity of collecting large amounts of data to characterize the variability and accurately estimate concentrations at particular points in the cave and at particular times. To the manager this variability suggests the risk of appreciable costs and open-ended studies. The common result of these conditions is that studies focus on collecting large amounts of data without reaching clear management conclusions, and that managers defer decisions until studies are completed. To avoid this "minimal-progress scenario" our program was designed to collect limited alpha radiation data from National Caves Association-member show caves and then to extrapolate the collected data to provide cave managers and the Alliance Agreement participants with a general understanding of the alpha radiation concentrations present in their show caves. To accomplish this we monitored all 71 caves studied to date at least once, and a few caves two or more times. During this monitoring we typically collected five to eight alpha radiation samples from the cave, and additional values from any attached building where employees spent any appreciable amounts of time. In one complex cave we collected 19 samples. We also conducted monthly monitoring of Tumbling Creek Cave at the Ozark Underground Laboratory. This is a large cave system with three sections that have dissimilar airflow patterns and alpha radiation conditions. At each of the show caves we determine which of the three cave segments in Tumbling Creek Cave (or all of them combined) was most similar to the microclimate conditions and airflow patterns encountered along the show-cave tour. We then indexed the measured mean tour route value from the show-cave against the same month value from Tumbling Creek Cave and then estimated the mean annual and mean monthly alpha radiation concentrations for the show-cave.

To date we have monitored 71 show caves in 19 states. There are six other states and Bermuda that have show caves. Table 1 summarizes estimated mean annual alpha radiation concentrations at the 71 caves.

Table 1. Estimated mean annual alpha radiation concentrations at 71 American show caves.

Estimated Mean Annual Alpha Radiation Concentrations (WL)	Number of Caves
0.00 to 0.10	18
0.11 to 0.20	14
0.21 to 0.40	12
0.41 to 0.60	9
0.61 to 0.80	7
0.81 to 1.00	4
1.01 to 1.50	3
1.51 to 2.00	2
3.51 to 4.00	1
6.01 to 6.50	1

The estimated mean annual alpha radiation in the 71 monitored caves is 0.53 WL. The distribution is skewed with 65% of the caves having estimated mean annual total alpha radiation of 0.40 WL or less; the median estimated mean annual alpha radiation is 0.22 WL.

In most cases employees spend more time working in caves during the summer travel season than during the rest of the year. Total alpha radiation concentrations in about 80% of the caves average 16 to 27% higher during the months of June, July, and August than the mean annual value. At the other 20% of the caves the values for June, July, and August average about half of the mean annual values for those caves. Each of the monitored show caves was provided with a report on the concentrations measured in their cave and with estimated mean concentrations for each month of the year.

At one show cave a small girl asked a cave guide whether all gift shops had caves under them. The answer is clearly no, but 23 of the 71 caves (32%) monitored to date do have gift shops or other buildings in which employees routinely work which are directly attached to the cave. This percent does not include buildings that simply provide security for the cave and are used only to enter or exit the cave (or in one case to view the natural vertical entrance into the cave). Mean annual alpha radiation in the caves directly connected to buildings averaged 0.90 WL; the median value for the 23 caves was 0.29 WL. Of the seven show caves with estimated mean annual total alpha radiation in excess of 1.00 WL five of these (71%) have buildings connected to them.

In many cases having a building connected to the cave decreases natural air exchange between the cave and outside air. In most cases the air in the buildings is warmer than the cave air and the warm building air reduces the rate at which cave air can exchange with surface air. This is especially true when exterior doors to the surface building are closed due to heating or air conditioning of the building.

Occupied buildings connected to cave air often have elevated alpha radiation. At caves with connected buildings we monitored the buildings as well as the cave air. Monitoring points were typically at locations where employees spent appreciable amounts of time, such as at cash registers and ticket sales counters. Thirteen of the 23 buildings directly connected to caves had locations routinely used by employees where total alpha radiation concentrations were 0.04 WL or more. Five of these buildings had alpha radiation concentrations greater than 0.53 WL; this value is the estimated mean annual alpha radiation concentration in the show caves that we have monitored to date. The highest alpha radiation concentration measured in any of the buildings was 5.94 WL. This was at a ticket counter located perhaps 15 feet from a door open to the outside and pleasant fall weather. Elevated alpha radiation in buildings was found even when the building temperatures were much warmer than cave temperatures.

To demonstrate that low concentrations of alpha radiation are present essentially everywhere we measured the concentrations at outside locations away from buildings near show caves at 14 locations in 11 states. Values ranged from <0.001 at three sites to 0.010 WL; the mean was 0.004 WL. At the mean concentration for a week a person receives an alpha radiation dose equivalent to a one hour long dose at 0.67 WL. The typical cave tour at National Caves Association member caves spends about 45 minutes underground at a median concentration of 0.22 WL. This is equivalent to a one-hour alpha radiation dose at 0.165 WL, which in turn is equivalent to spending 41 hours in outside air at a mean alpha radiation concentration of 0.004 WL. Given these values it is obvious that cave tours do not produce an appreciable health risk to individual cave visitors.

Owners or managers were interviewed at each cave during the monitoring work. The following summarizes findings from these interviews:

- The average number of hours worked underground per calendar year by those employees who do cave work for private and state-operated show caves is 270 hours. The range is from 5 to 1,200 hours.
- The average maximum number of hours that any employee at a private or state-operated show-cave works underground per calendar year is 456 hours. The range is from 10 to 2,000 hours.
- An average of 44% of show-cave employees who work underground are employed for a total lifetime career of less than four months. 27% are employed for a total lifetime underground career of four to eight months, and 29% have underground careers lasting over eight months. Most of those with careers lasting over eight months are promoted to supervisory positions and spend less time in the caves.
- Smoking is not permitted at any National Caves Association-member cave and that prohibition is enforced on employees, contractors, and visitors.

Management Strategies

ALARA is an acronym brought to the attention of the parties in the Alliance Agreement by OSHA. It stands for As Low As Reasonably Achievable. As related to the alpha radiation issue, it is the objective of the Alliance Agreement participants to ensure that show-cave employees are exposed to total lifetime doses of alpha radiation which are as low as reasonably achievable.

ALARA is a philosophy used by the Nuclear Regulatory Commission. The following reference to the ALARA philosophy is from Nuclear Regulatory Commission Regulatory Guide 10.8–Guide for the Preparation of Applications for Medical Use Programs; Section 1.3 As Low As Reasonably Achievable (ALARA) Philosophy: Paragraph 20.1 {c} of 10 CFR Part 20 states:

> "... persons engaged in activities under licenses issued by the Nuclear Regulatory Commission pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974 should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures, and releases of radioactive materials in effluents to unrestricted areas, as low as is reasonably achievable."

In addition, Nuclear Regulatory Commission Regulatory Guide 8.10 (Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable) and Nuclear Regulatory Commission Regulatory Guide 8.18 (Information Relevant to Ensuring That Occupational Radiation Exposures at Medical Institutions Will Be As Low As Reasonably Achievable) provide the Nuclear Regulatory Commission staff position on this important subject. We believe that application of the ALARA philosophy to the issue of alpha radiation in show caves is consistent with the approach taken by the Nuclear Regulatory Commission.

Earlier we mentioned alpha radiation standards in force in the mining industry. The mining standards basically specify that alpha radiation in working sections of mines should not routinely exceed 0.3 WL, and that employees working in mines must not receive in excess of 4 WLM of alpha radiation per year (which would equal 120 WLM of alpha radiation in a 30-year career). For the mining industry this is basically an ALARA standard. Planned ventilation is a critical part of the design of a mine, and a properly designed mine should be able to routinely maintain alpha radiation concentrations at 0.3 WL or below. At this concentration people can work full time and not exceed the 4 WLM annual total dose.

Remember that the relationship of lifetime dose to increased lung cancer risk is linear and that there is no safe threshold. There is nothing particularly safe or unsafe about the 4 WLM annual dose value; it is simply a reasonably achievable standard for the mining industry. Just because it is a reasonable standard for the mining industry does not mean or suggest that it is a reasonable standard for the show-cave industry. In reality, applying the 4 WLM annual dose maximum used in the mining industry to the show-cave industry does not decrease the total cave employee risk. Exposing twice as many people to half as much risk still equals the same amount of total risk. The objective in sound employee health and safety protection is to reduce the total risk rather than to spread the risk around. The suggestion that setting an upper limit of 4 WLM per employee per year in show caves is a health standard that protects employees is specious. If managers wish to spread cave time around among a larger group of employees to minimize guide "burnout" or for some other reason that is within their purview, but they cannot credibly view such actions as protecting employee health from the potential risk of alpha radiation or as a component of a cave radiation management plan.

As demonstrated by the Ozark Underground Laboratory monitoring, the estimated mean annual alpha radiation concentrations at show caves in the United States vary by a factor of over 500. Work patterns and other conditions at show caves also vary tremendously. As a result, it is our conclusion that the best approach for ensuring that total employee exposure to alpha radiation in the show-cave industry is as low as reasonably achievable is for each cave to develop and implement a cave-specific cave radiation management plan.

The Ozark Underground Laboratory and National Caves Association are developing a set of Best Management Practices (BMPs) for the show-cave industry. Application of these BMPs will result in decreased employee exposure to alpha radiation. Each cave will review the BMPs and determine which of them (or alternate BMPs) can be reasonably applied at their cave and will commit to following the relevant BMPs at their show-cave operation. A partial list of the draft BMPs follows to give the reader an idea of practices that can be used. Not all of these will be possible at all caves, and some may already be in place and simply need to be documented and continued.

1. Give visitors "cave rules" and other introductory information outside the cave except during bad weather. This reduces total underground time.

One cave gives an impressive steam engine demonstration outside the cave that reduces the amount of time spent in the cave during the tour. As an alternate, give introductory information in a cave area with low alpha radiation concentrations.

2. Reduce or eliminate underground activities that do not require the use of a cave. The snack bar in the Big Room of Carlsbad Caverns is an example of such an activity, but other tangential activities may exist at other caves. We do not recommend elimination of special events in caves such as Boy Scout camping, science schools, or other special events. However, to the extent reasonable the location and timing of these events should give due consideration to alpha radiation concentrations.

3. Conduct major construction or maintenance work during periods of the year when alpha radiation concentrations are relatively low. This applies both to show cave employees and to contractors. It is the responsibility of the cave owners to provide contractors with information regarding the alpha radiation in the cave. Employee manuals can be amended fairly easily to read "Contractors Safety Information." Our monitoring program provides estimated mean monthly alpha radiation values for each cave so that member caves can use the data in scheduling work.

4. Adjust cave tours to spend as little time as possible in higher alpha radiation areas, and as much time as possible in lower alpha radiation areas. This is facilitated by the alpha radiation monitoring that we have been conducting.

5. Prevent cave employees from sitting in cave air during rest periods between tours.

6. Minimize the duration of underground tours while still providing an adequate visitor experience. In some cases this may require removing tour "bottlenecks." Large tour groups move more slowly than smaller groups and much time can be spent waiting for the last people in a group to reach an interpretive stop. While smaller tour groups may require more guides and thus more underground work time by employees this is offset by less alpha radiation exposure for visitors. Show caves should minimize unnecessary exposures to visitors as well as to employees.

7. Ensure that occupied buildings are separated from cave air. In many cases this can be done fairly simply. At two of the monitored caves small vent fans were in use in locations where they prevented almost all cave air from entering the connected building.

8. To the greatest extent reasonable place only non-smokers in cave work jobs. The lung damage resulting from smoking may increase smokers' risks of lung cancer from alpha radiation to levels several times greater than those for non-smokers at identical alpha radiation levels. Research work with which we are familiar has not assessed the issue of whether it is necessary for smokers to actually smoke in elevated alpha radiation environments to increase their lung cancer rates relative to non-smokers.

Cave Radiation Management Plans

As discussed earlier, it is the objective of the parties involved in the Alliance Agreement to reduce total alpha radiation exposures of show-cave employees to ALARA levels. Because alpha radiation concentrations and other conditions vary widely among caves each show-cave will develop its own cave-specific alpha radiation management plan. The following summarizes the proposed requirements for such plans. The strategy and an associated guidance document were approved in principal by the National Caves Association in October 2005 with the intent to ratify them in 2006. There may be some changes in the proposed requirements prior to their ratification by the National Caves Association, but the following list summarizes the strategy that is being implemented:

- National Caves Association will establish a policy that, as a requirement for new or continued membership in National Caves Association, each member cave will develop a Cave Radiation Management Plan ("Plan") for their particular cave. The plan will follow a general outline developed by the Ozark Underground Laboratory working under an Alliance Agreement with OSHA.
- Each National Caves Association-member show cave is to prepare a Cave Radiation Management Plan. The National Caves Association will certify that final plans comply with the National Caves Association requirements for a cave-specific Cave Radiation Management Plan.
- The Title Page will include the following information: Name of the cave, author and job title, date of preparation, dates of any updates or revisions, and date of National Caves Association certification that the plan complies with National Caves Association requirements.

• Part 1 of the Plan will include results from the Ozark Underground Laboratory/OSHA study and Alliance Agreement. This will be provided by National Caves Association/Ozark Underground Laboratory.

• Part 2 will include copies of all alpha radiation monitoring results from the cave. This will be provided by Ozark Underground Laboratory

• Part 3 will require a summary of typical monthly underground work time and total employee exposure by month. Estimated mean monthly total alpha radiation values for the cave will be provided by Ozark Underground Laboratory.

• Part 4 will identify cave features of special significance to ensure that they are not adversely impacted by the Plan and to help readers of the Plan more fully appreciate the features.

• Part 5 will deal with employee training; there are several requirements: (A) Employees must be trained about the cave radiation issue. Basic information on cave radiation shall be included in employee handbooks where such handbooks exist; employee handbooks are strongly recommended. Periodic re-training is mandatory.

(B) A member of management at each show-cave must receive specific training in the cave radiation issue so that he can answer employee questions.

(C) Records must be maintained and included in the Plan indicating training on the issue.

• Smoking by employees, contractors, or visitors must be prohibited in show caves, and this must be enforced.

• Management actions to reduce alpha radiation concentrations in caves to ALARA levels must be identified and implemented. Actions currently taken which help achieve this objective should also be identified.

• Management actions to reduce alpha radiation concentrations in occupied buildings connected to caves or cave air to ALARA levels must be identified and implemented. Actions currently taken which help achieve this objective should be also being identified. In most cases elevated alpha radiation levels in occupied buildings due to cave air are unacceptable.

Summary

Alpha radiation is naturally encountered in cave air, but the concentrations vary dramatically among caves, and vary substantially in individual caves seasonally. Alpha radiation has been correlated with an increased risk of lung cancer, yet the credibility of the correlation relative to air encountered by employees in show caves is at least somewhat questionable. However, the approach we are taking is to presume that alpha radiation as encountered by employees in show caves is a valid employee health issue and should be addressed in a credible manner by management strategies.

The alpha radiation issue has been of concern to show-cave managers and cave conservationists for 30 years. During this time a substantial amount of money has been spent by the National Park Service in alpha radiation monitoring in caves and in record keeping of time spent by employees working underground. One positive result of the National Park Service monitoring program was that cave air from Mammoth Cave, which formerly was used to cool National Park Service administrative offices, is no longer used for this purpose. Aside from this, the National Park Service monitoring and record keeping has resulted in little or no reduction of total employee exposure to alpha radiation. During the same 30-year period private National Caves Association-member caves kept employees from working more than 700 hours per year in caves. This also resulted in little or no reduction of total employee exposure to alpha radiation.

We have outlined a strategy by which the National Caves Association and its show-cave members will concurrently protect show-cave employees, show caves, and show-cave businesses. Based upon some "back-of-the-envelope" calculations we believe that the total alpha radiation exposure of show-cave employees to alpha radiation can be reduced on a nation-wide basis by 20 to 30%, and at some individual operations by up to 70%.

The development of the strategy outlined in this paper has been a cooperative effort of the National Caves Association, Ozark Underground Laboratory, and OSHA and has been conducted under an Alliance Agreement. All parties have had valuable and cooperative input into the development of the strategy. Alliance Agreements provide for a cooperative (rather than adversarial) approaches toward understanding, assessing, and solving industry-specific problems that relate to employee health and safety. The resulting National Caves Association standards and the cave-specific cave radiation management plans represent industry standards and are enforceable by OSHA.

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STUDYING CAVE VISITATION TRENDS AT TIMPANOGOS CAVE NATIONAL MONUMENT AND NUTTY PUTTY CAVE

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Abstract

Visitation data is vital information for properly managing the use of caves. This presentation will show how visitation information has been collected, organized, and analyzed for the tours at Timpanogos Cave National Monument and uncontrolled visitation problems of the nearby Nutty Putty Cave.

Size, time, and date for each tour are recorded at Timpanogos Cave National Monument. The data was used to graph tour size frequency, seasonal and daily visitation fluxes, and the variability between tours sold and tours given.

At Nutty Putty Cave, a StowAway® light intensity datalogger was used to record the maximum light exposures over 15-minute intervals. This method collected high-resolution visitation data used to graph visitation by season, week, days of the week, and time of day. A surface register was used to collect visitation demographics. The data showed that local Boy Scouts troops were the largest visiting group with 17% of the total visitation and that National Speleological Society grottos were the smallest visiting groups of 1% of the total visitation.

Visitation data is a useful tool that can drive management changes. At Timpanogos Cave National Monument, we are currently associating resource violations (such as touching formations, littering, and leaving tours) with visitation trends to reduce visitation impacts. At Nutty Putty Cave, visitation information helped convince the Utah State Trust Lands that better management practices are needed. Having visitation information is vital to creating valuable change for these two heavily used caves.

Caves are managed by managing people. A common management concern is the negative, sometime irreversible, effects of over visitation. An often overlooked tool to managing caves is seeking to understand its visitation.

Visitation statistics were collected from tour operations of Timpanogos Cave National Monument and from the public access of Nutty Putty Cave. This paper shows the different purposes and techniques of collecting the visitor statistics in a tourist cave and a popular wild cave.

Timpanogos Cave

Timpanogos Cave National Monument is located about a 40 minute drive south from Salt Lake City and a 30 minute drive from Provo. The cave is located along the high cliffs of the American Fork Canyon within the Wasatch Mountains. Every visitor hikes 1½ miles gaining 1,100 feet in elevation along a paved trail to reach the cave. Due to being located at 6,600 feet in elevation, the amount of snow allows the cave to be open for only the summer season each year. In that 6-month season, an average of 69,439 visitors toured through Timpanogos Cave.

The tours through Timpanogos Cave offer a unique up-close and personal cave experience of a fault-controlled cave nicely decorated with an abundance of helictites and anthodites. The tours are limited to 20 people per tour at which visitors seem to be crammed in at each stop. The maximum daily visitation is about 1,100 visitors in 55 tours — that's a sold-out tour going every ten minutes.

The goal for studying visitation trends at Timpanogos Cave is to maximize resource protection, safety, and visitor's satisfaction while maximizing revenue. Some of the methods to accomplish this goal are:

- Publish the "best" time to visit.
- Higher use of volunteers and partnerships
- Provide incentives to visitors to come during slow hours or days
- Find the optimal tour size and daily tour densities

At Timpanogos Cave National Monument, visitation statistics are collected at the Visitor Center as tour times are being scheduled and at the cave entrance as tours are being given. So the number of visitors for each tour time is recorded twice.

Looking at the seasonal visitation (Figure 1), the highest average peaks fall along holiday weekends. The minimum daily visitations noticeably increase as schools are out of session. The overall visitation peak occurs during the hottest time of the year with the summer highs reaching over 100° F.

Daily visitation (Figure 2) is fairly constant throughout the day with a very broad peak around noon. Also the cave shows consistently larger average and maximum numbers than the Visitor Center.

Studying tour size frequency

A greater number of large tours occur at the cave to deal with complications such as late and early arrivals. As big tours are scheduled at the Visitor Center, even bigger tours occur at the cave.

Nutty Putty Cave

Nutty Putty Cave is the most heavily visited

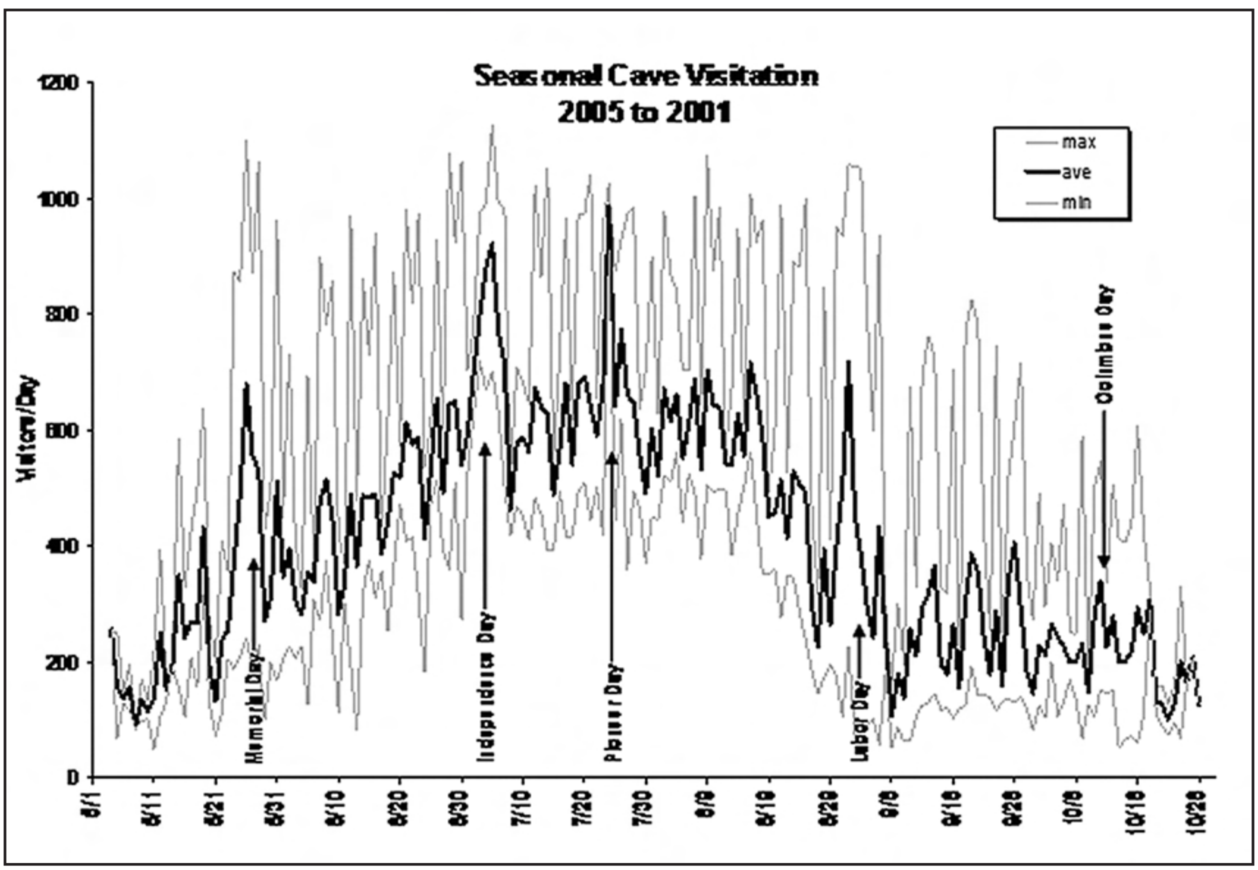

Figure 1. Seasonal visitation at Timpanogos Cave.

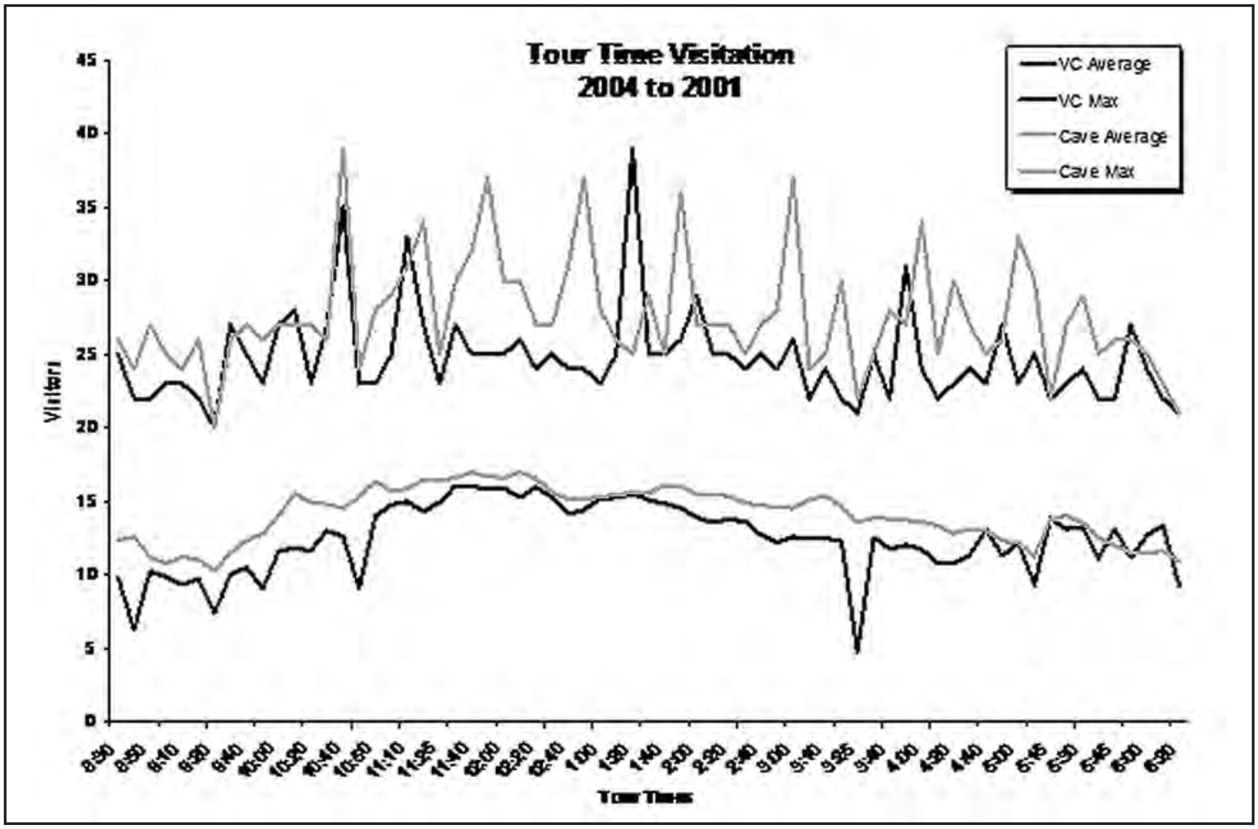

Figure 2. Daily visitation at Timpanogos Cave.

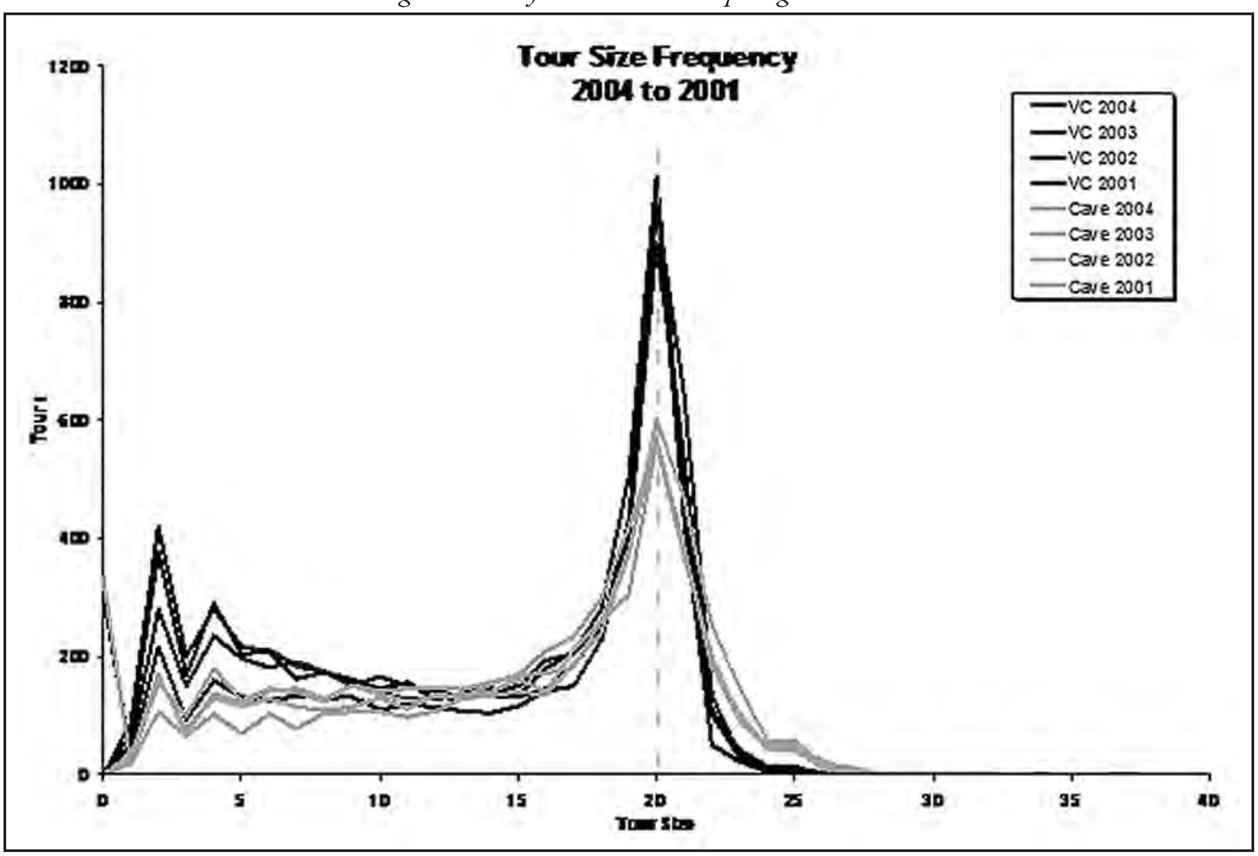

Figure 3. Tour size frequency.

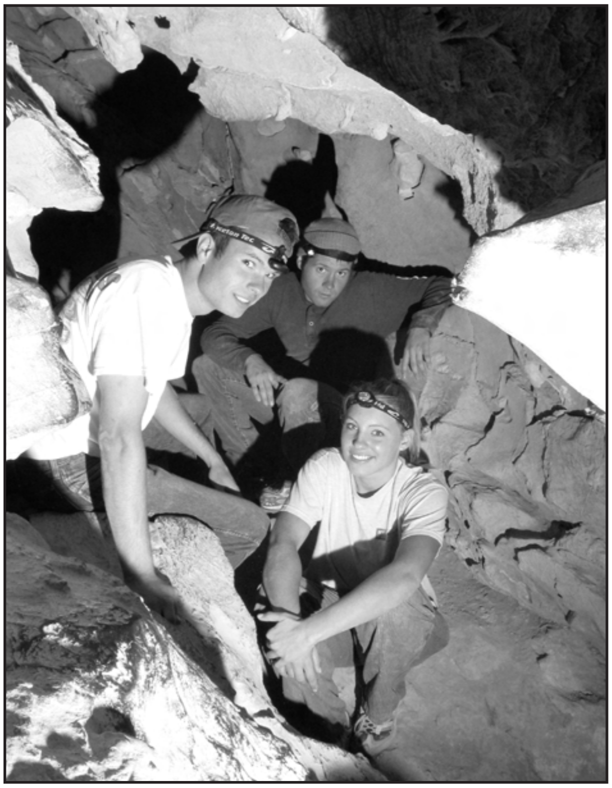

Figure 4. Typical outfitted Nutty Putty Cavers.

wild cave in Utah. Using a light counting sensor the annual visitation is estimated at over 4,909 visits – twice the combined visitation to all of the other Utah wild caves.

The main concern in Nutty Putty Cave is safety. A large percentage of the visitors are not properly prepared. They do not wear helmets, carry extra lights, or seek proper leadership or training. The fixed ropes for the short climbs in the cave are worn through their shields in a matter of months. Often trails of blood and other human waste litter the cave.

In 2004, the problem escalated with two full rescues occurring over Labor Day weekend. The local Utah County Sheriff's office and the owners, the Utah State Trust, initiated a meeting between the Boy Scouts of America, Brigham Young University, and Timpanogos Grotto to find solution to increasing liability risks. The visitation data gather has been a helpful tool in guiding the actions to implement proper cave management practices in this popular cave.

Figure 5. HOBO stowaway light intensity logger.

Visitation data was collected through two methods, a light sensing datalogger and a cave register. A HOBO Stowaway light intensity logger (retails for $191) was used to collect maximum light intensity readings every 15 minutes. The logger was then placed into a clear HOBO submersible case (retails for $39) and hidden in an out-of-reach location with the light sensor facing towards the cave's main path. A flip-top cave register was placed on the surface to record demographics, such as group affiliation and visitor's locality.

Before the light intensity logger was stolen, 9 months of continuous data was collected (Figure 6). Over a period of 288 days, 3,871 visits were recorded. This is an average of 13.4 visits per day. The logger showed that the cave was occupied 13.8% of the time.

An advantage of collecting visitation data through a datalogger is that the data can be filtered by date, days of the week, and 15-minute time slots. When studying the data graphed by time intervals (Figure 7), visitation trends can be seen. The bottom bars show the constant Saturday visitation. The next bars represent the most frequently occurring Friday night visitation. Surprisingly, almost all of the possible 15-minute intervals within a day recorded some visitation.

The surface cave register recorded the percentage of the cave's usage by organized groups (Figure 8). Amazingly, organized cavers or grotto members seem to have abandoned the cave. The main use was from Boy Scouts, Latter Day Saints church wards, and universities. So these groups are going to be included in implementing the future management solutions to improve the Nutty Putty Cave's safety problems.

Conclusion

Caves are highly limited resources. They can only maintain a certain amount of use before resource or safety concerns become overly evident. Seeking to understand visitation uses and trends can greatly aid in properly managing cave resources. Positive management changes are slowly being implemented at Timpanogos Cave and Nutty Putty Cave due to these visitation studies.

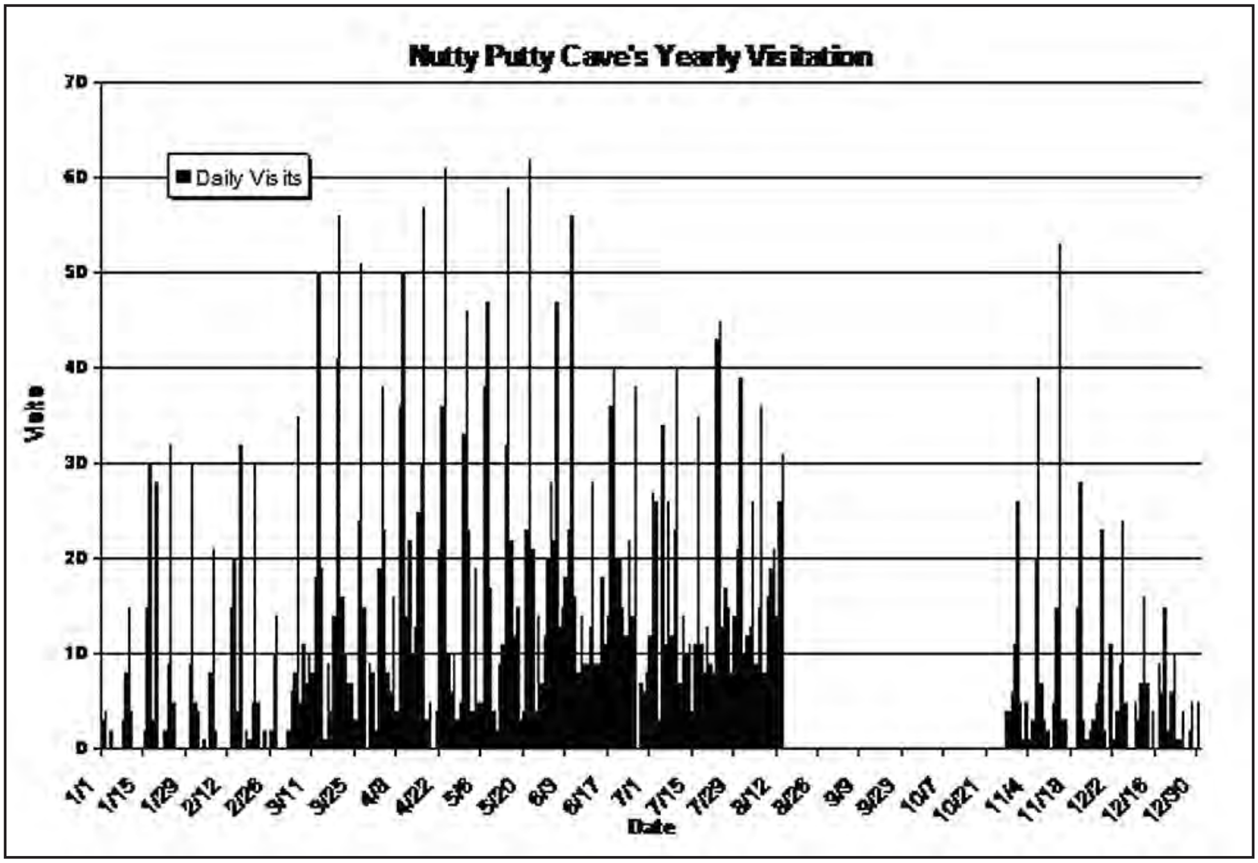

Figure 6. Daily visitation totals collected from Stowaway Logger in Nutty Putty Cave.

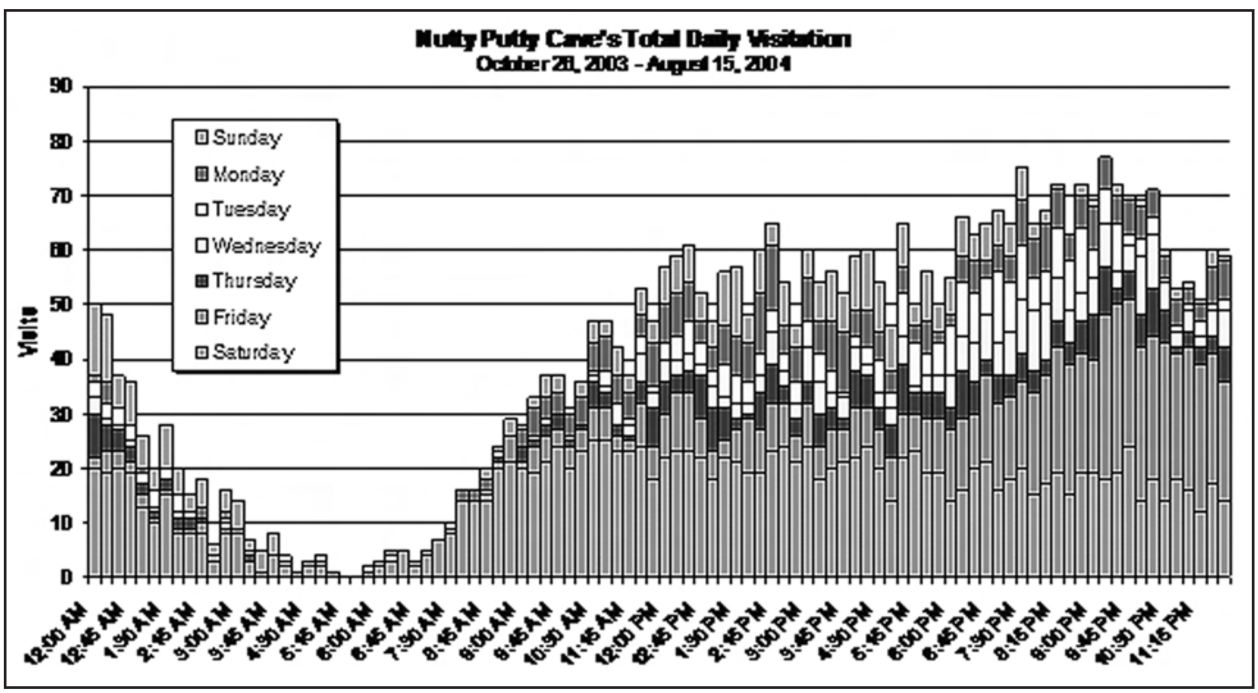

Figure 7. Accumulative visitation graphed in 15 minute intervals.

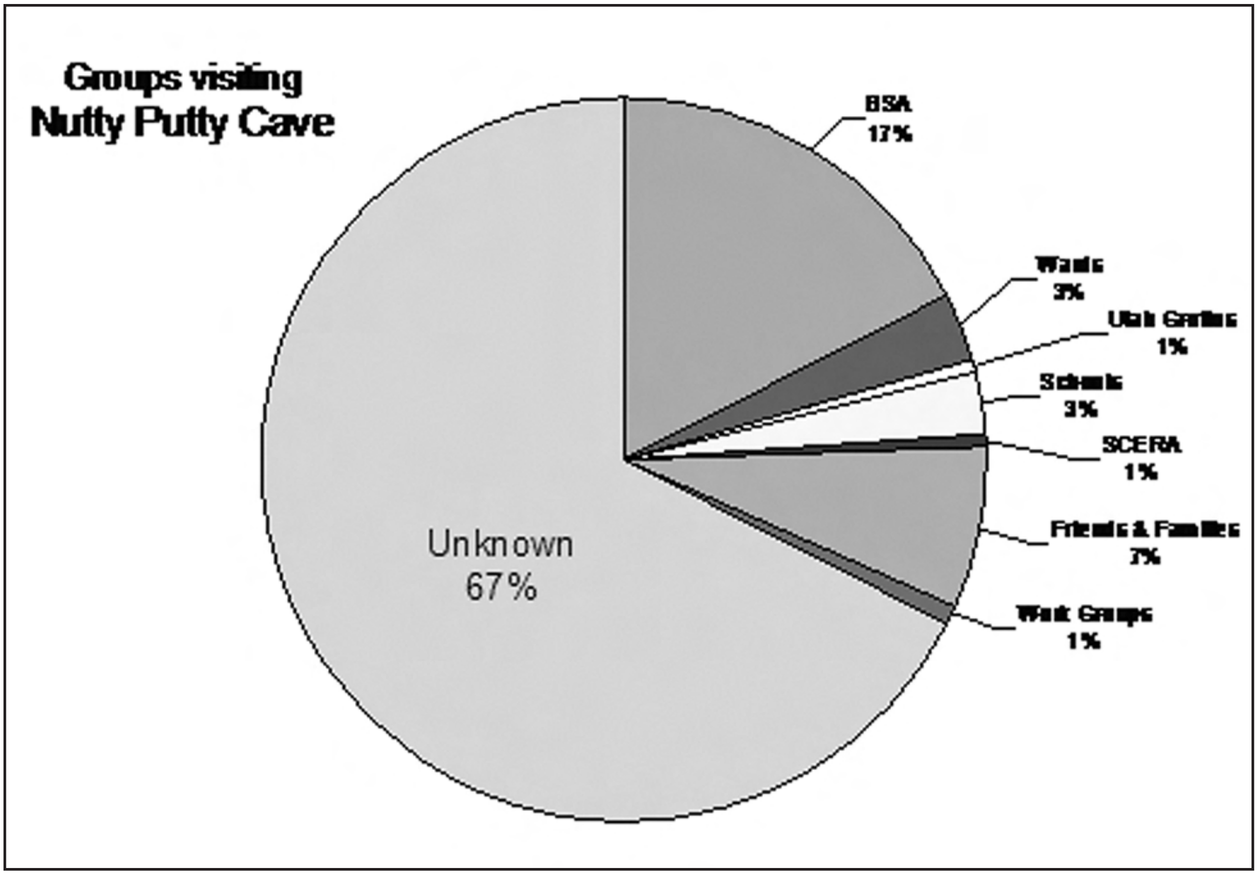

Figure 8. Percentage of group usage in Nutty Putty Cave.

Figure 9. Nutty Putty Cave Register.

Figure 10. TV coverage of a mock rescue at Nutty Putty Cave.

HISTORY OF RESOURCE MANAGEMENT: CONFLICT AND RESOLUTION, HOWES CAVE, NEW YORK

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Abstract

Howes Cave, the Howes Cave Quarry, Howe Caverns, Secret Caverns, and the McFails Cave Preserve of the National Speleological Society are at the center of a dramatic saga that illustrates the technical, economic, and social conflict between different perspectives of natural resource utilization. The local caves and their host, the limestone resources, are valuable as commercial tourist caves, non-commercial recreational caves, raw materials for the manufacture of natural and Portland cement, stone for construction aggregate, groundwater, and education. The most recent significant event in the saga occurred in 2002 when Cobleskill Stone Products started a redevelopment plan based upon a 1993 Masters Thesis at RPI by Clemens McGiver. The $7.4 million project is unique because it is the first in the USA that attempts to harmonize the interests of the aggregates industry, the commercial cave businesses, academia, and the community, including cavers. A new surface quarry is being opened and existing industrial structures are being renovated for new uses. The long derelict but historic Cave House Hotel at the entrance to the Howes Cave Quarry is being restored to create a national museum of mining and geology, while the historic and supposed collapsed Howes Cave is being reopened for tours. The project and associated projects are underway to define the limestone resources that could be mined, while protecting groundwater, wild cave, and commercial cave resources from both the potential effects of new mining and the current effects of conflicting agricultural, commercial, and residential land use.

CAVE AND KARST CENTERS OF EXCELLENCE

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Abstract

A Center of Excellence is a concept that brings together state-of-the-art practices, actions, and technologies on a specific topic or subject area. By this definition there are numerous Cave and Karst Centers of Excellence already in existence around the world. Identifying these Centers of Excellence is based on recognizing current activities taking place in that area and their mutual benefit to healthy cave and karst environments, and to the benefit of the people. To achieve this goal, partnerships among governmental agencies as well as academic, non-governmental-organizations, private, and international partners can be brought together. These partnerships will help build an infrastructure to raise awareness and foster an understanding of cave and karst resources within a region and around the country.

The goal of a center of excellence should be to enhance resource protection and management through the collaboration and cooperation of the partners and the education of the public. As a Center of Excellence the cooperators focus on objectives that highlight the best management practices of cave and karst resources and their interpretation and environmental education of the public.

Major objectives in establishing a Cave and Karst Center of Excellence are to: (1) Develop working groups and partnerships focused on cave and karst actions and issues: Cavers, Academia, Governmental agencies, Land Conservancies, and Industry

(2) Foster, concentrate, and develop technical expertise for the protection, conservation, and restoration of caves and karst terrains. Work with local and regional industries and entities to develop the best management practices regarding cave and karst resource uses; Cave Tourism; Logging, Grazing, Oil, Gas, and Mineral Development; Urban Development Projects.

(3) Establish community based tourism opportunities to communicate with and educate the public about cave and karst environments.

Backcountry cave tours, Traveling cave/karst exhibits, Karst maps with educational driving tours, Cave/karst Brochures and videos, Show Cave Development and marketing.

Cave and Karst Centers of Excellence provide recognized leadership to communities and regions. They support local economy in a sustainable manner by educating the public and protecting cave and karst resources.

Introduction

Cave and Karst Centers of Excellence are characterized by their interaction with all aspects of the natural and human environment. This means that the various aspects of a community, region, and/or broad geographic areas are brought together in an effort to apply the best management and stewardship practices for living on karst terrains.

Caves and karst lands contain remarkable and often unique resources that add to the richness of regional natural and socio-economic values. Of primary concern in karst lands is the relationship between the surface and the subsurface and the rapid and direct recharge of critical aquifers. An informed and knowledgeable stewardship of karst lands is vital to the protection of its aquifers, the health of its ecosystems, and the prosperity of local communities. Considerations for successful living on karst terrains include its delicate ecosystem and an understanding of the complex nature of karst land forms which require the recognition of special engineering challenges.

Caves can be a major component of karst lands. They contain a variety of resources. These resources include well preserved archeological sites of ancient cultures that predate the modern era, the fossilized remains of unique animals that roamed the plains and mountains over 50,000 years ago or swam in seas known to have covered the land some 260 million years ago. Many caves provide critical habitats for colonies of bats that are important to the agricultural industry. These bats consume literally tons of insects each summer night, protecting crop from pest and reducing the need for pesticide applications. Other animals using the caves make up a unique and very delicate ecosystem that is integrally tied to the surface. Some of these species, such as newly discovered microbes, are proving to be highly valuable in medical research for developing new drugs to combat diseases such as cancer. Other species of microbes are being studied to understand possible links of life on Mars. Research being conducted in caves and karst lands expands our understanding of our geologic, hydrologic, and biologic resources and how our daily lives are affected by living in association with these karst lands.

All of these factors need to be considered when implementing development plans on karst lands and achieving excellence in successful living there. Three primary objectives in establishing a cave/karst center of excellence are:

(1) Develop working groups and partnerships focused on cave and karst actions and issues,

(2) Foster, concentrate, and develop technical expertise for the protection, conservation, and restoration of caves and karst terrains,

(3) Establish community based sustainable tourism opportunities to educate the public about cave and karst environments.

By incorporating and implementing these three primary objectives into the way communities and regions operate in karst lands the overall understanding of these natural systems in karst lands will increase and the protection of these systems will become a way of life.

Develop Working Groups and Partnerships Focused on Cave and Karst Issues

The ground work of establishing a cave and karst center of excellence is based on recognizing the benefit of a healthy cave and karst environment and its mutual socio-economic benefit to the people. To achieve this goal, partnerships among city, county, state, and federal agencies as well as private and non-governmental-organizations, and international partners should be developed. These partnerships will build a network and infrastructure to raise the awareness and understanding of cave and karst resources in the local communities. Among the groups critical in building such a partnership are speleologists, academia, governmental agencies, and affected industries.

Speleologists often have the best understanding of karst systems. They are on the front edge of cave exploration and the research. They conduct research needed to understand the hydrologic connections in large regional systems and other critical aspects of the karst ecosystem. Speleologists also have the best information on cave locations and inventories of the various resources in the cave. The caving community provides the on-the-ground support needed to carry out many of the projects designed to protect and enhance cave and karst resources. They are the eyes and ears out in the field that can be vital in determining the health of the cave ecosystem over a long term and being able to detect change in the biological communities in the cave systems.

Developing partnerships with academic institutions is of great importance in establishing credible scientific and research data and information bases. Universities and academic institutions with an emphasis in cave and karst studies have focus groups and students that can work on specific projects through cooperative studies and can be set to work on individual issues or on regional problems. Working through a university can provide the long term continuity for major projects. Funding opportunities through grants can be more easily obtained.

It is essential to form partnerships with governmental agencies at all levels: federal, state, and local. Federal agencies often have large tracts of land containing karst terrain and may need the help of interest groups and subject matter experts to develop karst sensitive management plans. They can also be instrumental in karst land protection by the type of land management policies and direction they put forth.

Municipal and provincial governments may de faced with expanding populations and urban growth on karst lands. Ordinances, building codes, and special design features can factored into new developments to help prevent environmental problems and preserve a healthy karst ecosystem. In this way the karst ecosystem and the developing human community can both benefit. As agencies begin to understand more about the nature of karst and the integral connection between the surface and the subsurface it will be easier for them to make the right decisions concerning the appropriate use and management of cave and karst resources. Agencies can provide a critical role in promoting proper land use ethics.

A variety of industries may make up some of the primary users of karst terrains. They are critical in the overall mix of cooperators and partners. These industries have the expertise and technical background to know what techniques and operating methods may be applied or developed that will have the least impact and most protection of cave and karst lands. As affected industries begin to understand how their activities can impact sensitive underground resources and create economic risks and safety hazards for local communities they may become more interested in helping develop solutions to the problems.

Develop Technical Expertise to Protect and Conserve Caves and Karst Terrains.

Working with local and regional industries and entities to develop the best techniques and operating procedures for use in regions is vital to successful excellence in living with these terrains. Partnerships can be formal written agreements or can be long-standing cooperative relationships. In either case it is an opportunity to consult with industries doing business on karst lands and discuss the inherent risks and impacts to their operations and to the long term health of karst terrains and resources. By working with the industrial users on karst lands protection and conservation of cave and karst resources can be achieved.

The oil and gas industry can encounter severe problems while drilling on karst lands. These include the collapse of drilling rigs into shallow cave systems, lost circulation problems, unsuccessful cementing programs, ruptured pipelines due to doline collapse, and others. The industry does not want to encounter these problems. They cost large amounts of money to correct. These operational problems may also cause direct and/or major cumulative impacts to the cave and karst systems. Lost circulation problems, leaking tank batteries and pipelines, and leaching of reserve pit contents can severely degrade groundwater supplies and contaminate resurgences, water wells, and riparian ecosystems. In working with the oil and gas industry a three-phased approach to resolving these problems has been developed.

The first phase is the detection of potential cave or karst features that could be impacted. Detection methods can include field exams, remote sensing, and geophysical methods. The second phase is the avoidance of these features by moving the operation to a less critical location. Where caves are known and have been surveyed the location of passages can be overlaid on surface maps and analyzed. This information can be used to avoid the placement of roads and other facilities over the top of sensitive karst features. The third phase is the mitigation of impacts that can not be avoided. The mitigation can be in the form of special drilling, casing, and cementing procedures and the use of specially designed reserve pit and recovery systems. These should all be discussed and designed in collaboration with the oil and gas industry.

This three phased approach of detection, avoidance, and mitigation can be used with other industrial operation on karst lands. For logging operations in karst lands specific cave entrances, insurgences, and resurgences can be identified and avoided during logging operations. Buffer zones of 200 meters and more can be left uncut around cave entrances and resurgences. This will help protect the water shed entering the cave from large accumulations of silt and slash debris. Another method of protecting the cave ecosystems are to avoid locating slash piles in dolines and cave entrances. This will ensure the normal and unrestricted flow of water and nutrients into the cave systems and eliminate the accumulation of highly acidic waters entering the system from the leaching of tannic acid from the slash piles.

The grazing and cattle industry can have detrimental affects on cave and karst ecosystems. Cattle often congregate around watering holes such as cave entrances and resurgences. They beat down the vegetation and compact the soils. Additionally, fecal material enters the system and can dramatically change the nutrient and micro fauna makeup of the natural system. Working with the ranching community to fence off these critical areas can help protect these delicate subterranean systems. Water can be piped from the springs to drinkers at alternate locations. Livestock feeders can be located away from these sensitive areas and help disperse the impacts of grazing.

Urban development projects can have a multitude of problems associated with building on karst terrains. Early meetings between speleologists and city and community planners are essential for identifying potential problems and outlining land development codes for karst terrains. Identifying critical areas not to build and creating natural preserves as part of the community development is a basic part of the planning exercise. Mapping the karst features and conducting inventories of resources to determining the best locations for roads, utilities, sewerage treatment facilities, landfills, and other essential infrastructure components is critical. Another essential part of the overall plan should be monitoring systems to tell if the conservation methods are working.

Establish Community Based Sustainable Tourism and Public Education Opportunities

Tourism is an emerging way that communities are diversifying their economies. Tourism must be designed to take advantage of the positive aspects a community has to offer and not to merely open their doors to anyone that wants to drop by. This means to consciously look at the resources they want to showcase and develop strategies and plans that can successfully offer these resources without degrading them over a long period of time. This is what sustainable tourism is. The other essential part of the tourism package is the community. It is important to ensure the involvement of the community when developing such a tourism economic development package. If the community is part of the overall picture everyone will benefit. The spin-off businesses such as hotels, restaurants, guide services, and others provide a broader base of community involvement and ownership while generating its economic returns. Several types of tourism packages can be offered that attract visitors with a variety of skill levels and interests.

This is the case in the Ipporanga area of Brazil. The primary economy of the local community had been logging until the government stopped all logging in the area to protect some of the endangered trees in the area. Without the logging industry the local community looked to their other natural resources for a source of income. With an abundance of world class caves they began conducting cave tours. As visitors came in, the community began to develop hotels, restaurants, and shops to support their emerging tourist industry. This new industry involved a large portion of the local community and provided them a steady source of income that was spread throughout the village. Some of the hotels have Web sites and do a good job of advertising and promoting cave conservation. By working with the local guides and giving them factual resource information about the caves and karst systems of their area the guides were able to modify the content of the talks they gave to visitors and pass along more environmental messages about their natural resources. The guides also gained a greater understanding of the cave and karst systems and a better appreciation of the resources. This higher level of understanding and appreciation then translates into better protection of the natural systems that provide their village its economic support. The entire community is involved with the karst lands and have a vested interest in their protection and health.

Through conscientious and careful advertising, messages about the importance and fragile nature of caves and karst lands can be passed on. Information about responsible land use ethics and the interrelationship between the surface and the subsurface can be interpreted. Information about how to safely explore and enjoy the world beneath our feet can be explained. This will also help reduce accidents, fatalities, and misadventures of visitors. Working in partnership with a local tourism office provides a wide array of advertising and communication media not available to individual businesses. This media exposure would assist tourism interests in showcasing certain caves, and pass on information about responsible land use ethics associated with karst resources.

Backcountry cave tours can offer a special type of tourism aimed at the more physically active visitor. They provide a unique and personal way of relating important information to visitors. Local guides can give the tours and inform the visitor about the local customs and uses of the caves in the area. Interpretive information can be given to the visitors to aid in their understanding of the natural ecosystems and the importance of the karst resources to them. This is an opportunity to put into practice many of the principles of cave conservation and ethics. Trails leading to the caves and trails through the caves can be developed to minimize the cumulative impacts of foot traffic. Important concepts of leaving what you find and not disturbing the native wildlife and speleothems can be explained to the visitors.

Traveling cave and karst exhibits give people an opportunity to learn about caves and karst terrains in a more structured setting. Information can be presented in a controlled environment and in a more ordered fashion. Schools and communities can take advantage of traveling exhibits as part of basic education and community involvement programs. Many people can be reached through the use of exhibits that may not other wise visit a cave or have the opportunity to learn about the relationship between the surface and the subsurface in karst lands. Traveling exhibits can be exciting and interactive with a variety of interpretive messages. Traveling exhibits can be large structures requiring elaborate set up and multiple speleological themes or they can be as small as a table top display. In either case they are sources of public interest and provide a focus on the ecosystems beneath our feet. They provide an opportunity to interact with an interested public and transfer important information about healthy living on karst lands.

Educational karst driving tours with karst maps that explain the features being seen is a good way to introduce people to the ideas of karst terrains on a regional scale. These can be developed and promoted throughout large areas and give the visitor a broad understanding of how the systems are tied to one another. These tours can be tied to geologic and cultural aspects of a regions history. A karst travel guide and information brochure can be developed through a collaborative effort between the local communities and the regional geological survey to produce a karst map with points of interest. The karst map and brochure could provide the visitor with the basic information about the different kinds of caves and karst lands in the region. Additional information could tie in the various aspects of karst lands and their importance to groundwater recharge, wildlife habitat, cultural heritage, and geologic interpretation. Audio cassettes and CDs can also be produces to go along with the maps.

Cave and karst brochures and publications are vital ways to get information across to the visiting public. They can present quick informative messages or detailed information on complex issues. Brochures provide an inexpensive way to help advertise and attract visitors to an area. They can give information on what is available to the tourist and what they can expect. The basic information of what is available, where it is located, whom to contact, and how much it costs is easily conveyed in a brochure. A colorful and well designed brochure can be a powerful advertising tool as well as being an instrument for disseminating conservation messages and basic safety practices. More detailed publications can provide the space for a larger story about caves and karst resources. They can give an in-depth look at the interrelations between the surface and the subsurface. Special publications can describe the specific geology, biology, hydrology, and cultural interests of the caves and region.

Show caves are the crown jewels of a karst area. They can attract large numbers of tourists and provide an underground experience to the general public with little risk and effort. Show cave tours can provide a wide variety of interpretive massages and give the visitor of what it is like to be inside Earth. A show cave experience has the potential to inspire visitors to know and understand more about caves and karst terrains. They can be exciting and educational. Development of good marketing plans through partnerships with other cave and karst related enterprises will help round out an over all package for successful karst tourism. Marketing strategies can include Web sites that provide information about caving interests and available tours and contacts. These Web sites can be linked to tourism Web bases with information about accommodations, restaurants, and links to other cave based Web sites that connect the visitor to local caving organizations, cave conservation organizations, and virtual cave web.

Conclusions

Cave and karst centers of excellence develop through partnerships in local communities and industries to raise the awareness of how caves and karst terrains affect our daily lives. Their goal is to enhance the protection and conservation of cave and karst resources through educating the public on how to balance surface uses with subsurface connections and ecosystems. Areas working towards this state of excellence utilize the experience and expertise of local industries to help solve problems associated with development on karst terrains and offer avenues for communities to realize economic benefits from their cave and karst resources that are compatible with the long term protection of those resources. To implement the concept of a cave and karst center of excellence the first step is to Identify the primary partners in the area. Second is through collaboration with the partners identify the major issues and threats to karst lands and community development. Third is identify opportunities for collaborative problem solving. Forth is to identify areas to engage the public in cave/karst education and tourism opportunities. The partnerships and working groups that are developed must be kept viable and in constant communication if a true excellence of living on karst lands is to be achieved. The health and prosperity of the community and the karst is at hand.

COLLABORATIVE EFFORTS BETWEEN UNIVERSITY AND NON-PROFIT GROUPS IN THE EVALUATION OF CAVE AND KARST RESOURCES.

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Abstract

The Hoffman Environmental Research Institute participates in ongoing interactions with non-profit groups needing cave and karst property evaluated for purposes of resource protection. These projects demonstrate techniques for evaluating cave and karst properties. A work plan was formulated in collaboration with The Nature Conservancy. Field methods involved in the project included cave survey and inventory, biologic specimen collection, a dye trace, water quality sampling, and photo documentation. GIS methods were then employed to present the findings of the field methods. The results of the study were used for The Nature Conservancy to help evaluate the resources they have. In Monin Cave, the survey and inventory has been completed, with a dye trace performed to understand the hydrology between two sections of cave on the property. Several cave adapted specimens were found at both sites, these are being classified by The Nature Conservancy biologists.

Introduction

The Hoffman Environmental Research Institute has been steadily building a relationship with the Kentucky chapter of The Nature Conservancy. The Hoffman Institute studies best management practices and other resource protection methodologies in karst and other rural areas in order to enhance environmental quality. The Institute is involved in developing specialized GIS tools to support the projects involved with resource management, particularly with regard to karst. The Nature Conservancy is a leading international, nonprofit organization dedicated to preserving the diversity of life on Earth. They strive to preserve plants, animals, and natural communities by protecting the lands and waters they need to survive. The organization is sectioned into chapters, representing the state they are located in; the specific section for this project area is the Green River Watershed.

The Hoffman Institute was originally introduced to The Nature Conservancy through a grant to buy 130 acres of rural land for Western Kentucky University. The relationship was built through ensuing work done in Metcalf County, Kentucky, on the caves of the Dry Fork area. The Nature Conservancy invited the Hoffman Institute to pay an initial visit to two sites to evaluate the potential for the caves, one located in Green County and the other in Adair County, Kentucky.

Project Areas

Monin Cave is located in Green County, Kentucky, near the town of Crailhope. Garnett Cave is located outside of Columbia, Kentucky, in Adair County. Monin Cave is located in the St. Louis Limestone, where Garnett Cave is in the Fort Payne Formation.

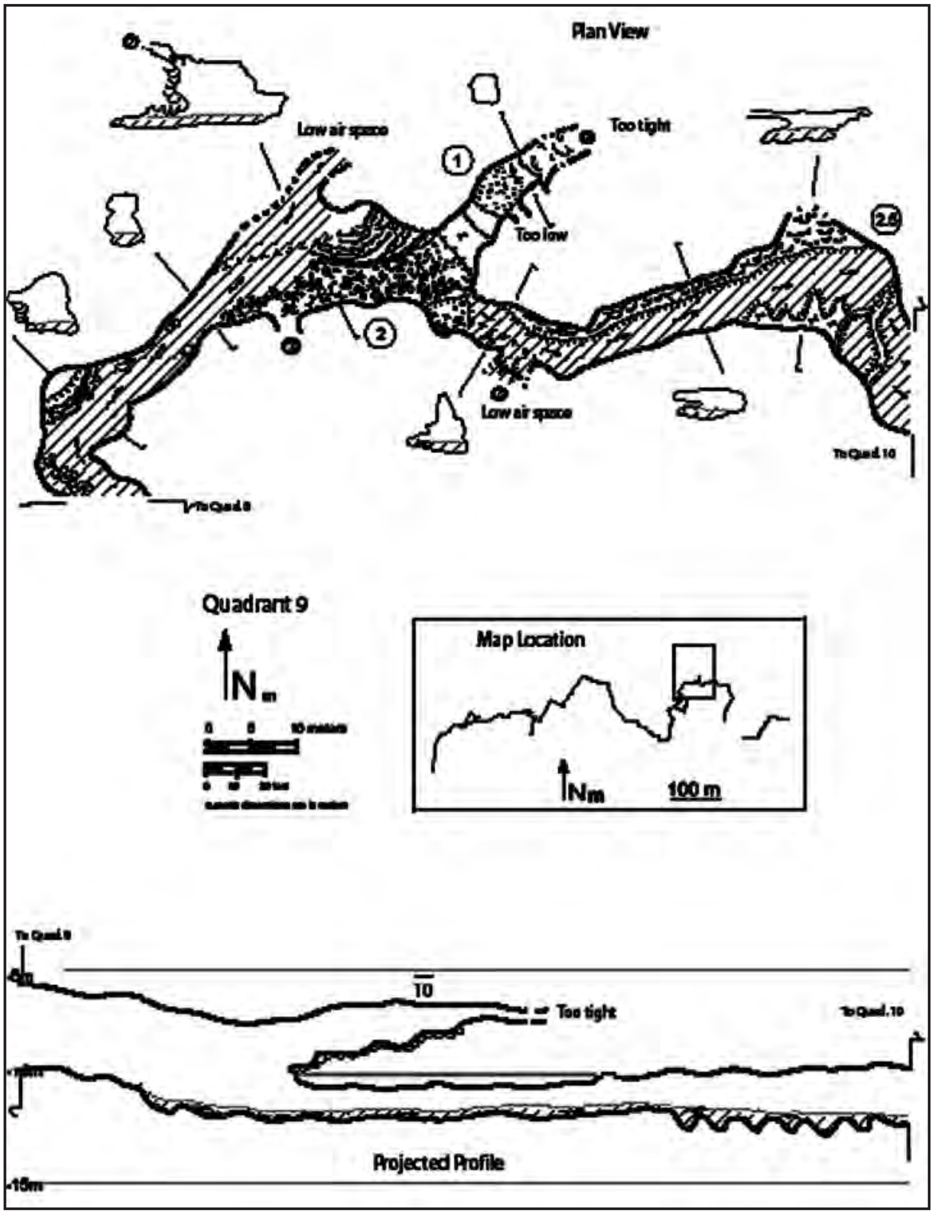

Figure 1: Finished Quadrant 9.

Field Methods

A work plan was developed with The Nature Conservancy to evaluate the two cave systems. A cave survey was conducted following standards set by the Hoffman Institute. The GPS data was taken by a Garmin Legend with accuracy of up to 10 meters. Along with the cave survey, a resource inventory was completed. Water chemistry measurements including temperature, pH, and conductivity were taken at both locations. Photo documentation was performed on all trips. A dye trace was performed at Monin Cave. The Nature Conservancy also asked the Hoffman Institute to perform a biologic collection of stygobites from both caves. The samples were then forwarded to scientists at The Nature Conservancy for identification.

Results

After the completion of the cave survey, the information was compiled into the Compass cave survey program. It was georeferenced using the GPS locations acquired in the field. This data was used to complete the cartography of each of the caves. Due to the size of Monin Cave, a quadrant map format was used. The Compass data was also exported as a shapefile. One shapefile was used to import the line plot onto a topographic map of the region in ArcGIS. Other shapefiles were modified to be used as a catalog for the resource inventory. These files were then added as layers in ArcGIS. An interactive map was created in ArcGIS displaying different inventory layers, such as locations of

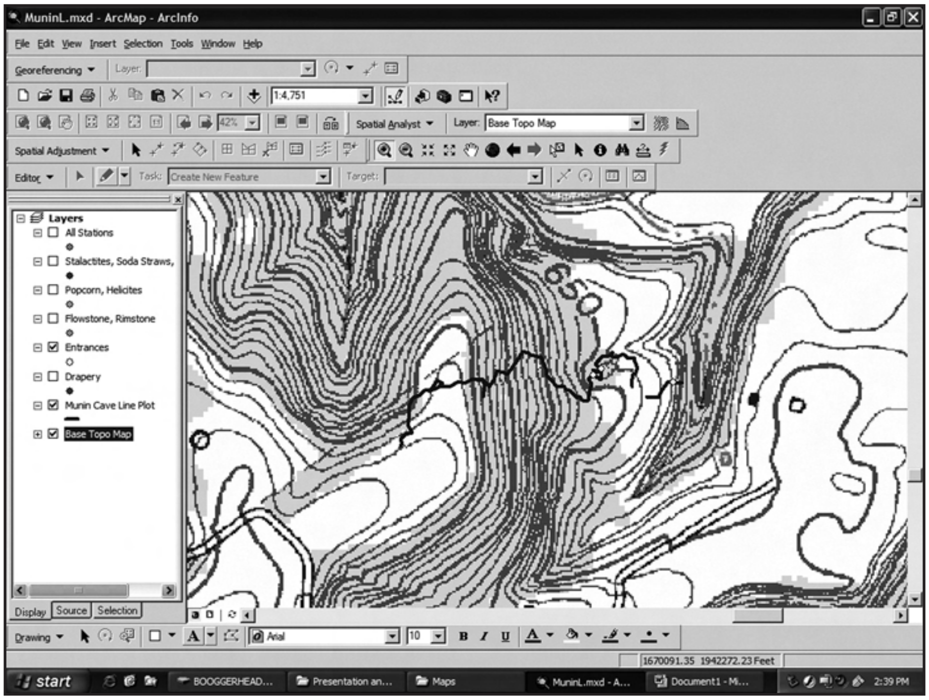

Figure 2: Inventory line plot in ArcGIS.

different speleothems in the cave. The results from the dye trace at Monin Cave provided a positive conclusion that the stream in Monin Cave was the stream that came out at Monin Spring. This was added as another layer to the interactive GIS map.

Future Work

The above details the preliminary work done at Garnett and Monin Caves, future work will directly correlate with the needs of The Nature Conservancy. It has been planned to try survey pushing the hydrologic connection between Monin Cave and Monin Spring. When the dye trace was performed, a visual hit was expected, due to the locations on the topographic map. A positive hit was obtained, but not in the time frame expected. Investigation of the passage in between might answer the time question. An overland survey needs to be conducted to determine the accuracy of the GPS placed points.

More information about Garnett Cave also needs to be obtained. There is a local rumor that there is another entrance to the cave, which was not found during survey. The topographic map shows an old homestead with a possible spring source in the direction of the survey. A clean-up project for this cave will be coordinated with the local grotto to take out glass and other debris that has washed into the cave.

Conclusions

The Hoffman Institute worked with The Nature Conservancy to develop and conduct a work plan for the evaluation of Monin Cave and Garnett Cave. The collaboration in this project is beneficial to both parties. Field methods and technical skills are built by students and associates of the Hoffman Institute that are transferable to other projects. It also builds a relationship with other agencies and the Institute is involved in providing services to the Commonwealth of Kentucky. The Nature Conservancy benefits by gaining knowledge about the systems they are seeing to protect. It helps drive the conservation-decision process for where they should work and what is required to conserve certain systems.

Acknowledgements

The Hoffman Institute would like to acknowledge the Center for Cave and Karst Studies for assistance in the dye trace. We would also like to thank The Nature Conservancy for their dedication to this project. Thanks also go out to the individuals who have helped: Joel Despain, Brad Hacker, Carrie Crockett, Pete Reutter, Andrea Croskrey, Angél Cortes, Pat Kambesis, Richie Kessler, Chris Groves, Wendy Breatheren, Mark Phillips, Todd Armstrong, Jeremy Tallent, Bruce Hatcher, Rick Olson, and Melissa Hendrickson.

DIGGING: GUIDELINES FOR CAVERS AND RESOURCE MANAGERS

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Abstract

Most cave entrances occur by natural happenstance rather than as an intricate part of the formation of the cave itself and the vast majority of caves have no entrance enterable by man. In the geologic lifetime of a cave any number of entrances may have opened and closed through natural processes. A surprising number of caves in the U.S. were discovered using some form of excavation or "digging" by cavers. Pursuing obvious "digs" is the next logical step in the process of searching for and inventorying caves. A variety of excavation techniques are employed ranging from removing soil and rolling a few rocks out of the way to "rock shaving" using micro-blasting techniques to using heavy equipment such as a backhoe. Digging for new caves and the techniques used for the excavation must be compatible with the overall land use regulations for the specific area. The techniques used for digging on highly protected lands such as wilderness areas should cause minimal disturbance to the surface zone and within the cave. The creation of a new entrance may reveal a significant resource not previously known and increase the natural value of the area. However, digging also may create negative impacts to the cave ecosystem and affect mineral growth by changing airflow patterns in the cave. Alterations to the surface zone immediately surrounding the new entrance may impact drainage, sedimentation, and energy inputs to the cave.

We cannot protect a resource that we have not identified, but we don't want to unnecessarily damage the resource in the process of discovery. In most cases, digging to search for a "new" cave or to reopen an old entrance is appropriate, but we must remain aware of possible environmental impacts and dig softly.

Introduction

Cave entrances provide links from the surface to the subsurface. Entrances provide points of air and energy exchange as well as routes for animals (including people) to enter and exit the cave. Most cave entrances occur through natural happenstance rather than as an intricate part of the formation of the cave itself (White 2005). The vast majority of caves have no entrance enterable by man (Curl 1958). In the geologic lifetime of a cave, any number of entrances may have opened and closed through natural processes.

As cavers continue to search for "new" caves and passages, a range of excavation or "digging" techniques are being employed. A surprising number of caves in the U.S. have been discovered by some form of digging by cavers. Digging may well account for the majority of current discoveries in the more popular caving regions. Pursuing obvious digs is the next logical step in the process of searching for and inventorying caves. Discoveries made possible as a result of digging have certainly increased our knowledge of the cave resources of the world. Many well known commercial caves have artificial entrances and sometimes tunnels connecting different sections of natural passages. Examples of caves with dug entrances include Carlsbad Caverns, Flint Ridge, and Lechuguilla. Most commercial caves have undergone considerable modification of the entrance and passages to make the caves accessible to tourists.

The opening (or closing) of a cave entrance may cause changes in the circulation of air or energy and sometimes alter hydrologic characteristics within the cave. In most cases, the changes to the cave environment will be minimal, but careful observation of the conditions in the cave may suggest deterioration in the condition of mineral formations or a loss of habitat. Cavers and resource managers need to be aware of these potential changes caused by the creation of an entrance and sometimes do remedial work around the entrance to control potential damage to the cave resource. The purpose of this paper is to present the pros and cons of excavating new cave entrances and suggest ways to minimize the impacts to the cave environment.

Digging Methods

The methods employed to open or enlarge an entrance or cave passage may range from simply moving a few rocks out of the way to a major excavation using heavy equipment (Davis 2005). An online journal containing detailed discussions of digging techniques may be found at http://www.cavediggers.com. A general list of digging techniques includes:

- Moving rocks or sediments by hand
- Hammer and chisel
- Rock shaving with soda-straw explosives
- Blasting
- Heavy equipment — backhoes
- Heavy drilling to intercept cave passage

The first three of these techniques are generally low-impact methods and create a very controlled excavation. The soda straw technique does not cause a true "shock wave" explosion or blast but works by pistol powder expanding in a propagating fashion to create enough pressure to split the rock (Figure 1). Cave diggers tend to be very inventive and a variety of techniques may be employed at any given site (Passerby 2002).

Rarely, more intensive techniques including "hydro-mining" using high pressure jets of water and vacuuming sediments using a commercial sewer cleaning service may be employed. The scene on the surface at some cave digs using heavy equipment resembles a mining operation while the work is in progress (Figure 2). These more costly activities are normally conducted by a land owner willing to bear the expense to locate or develop his cave, possibly as a commercial operation. Reclamation of these sites may take several years, but given time the cave environment and animal populations should recover.

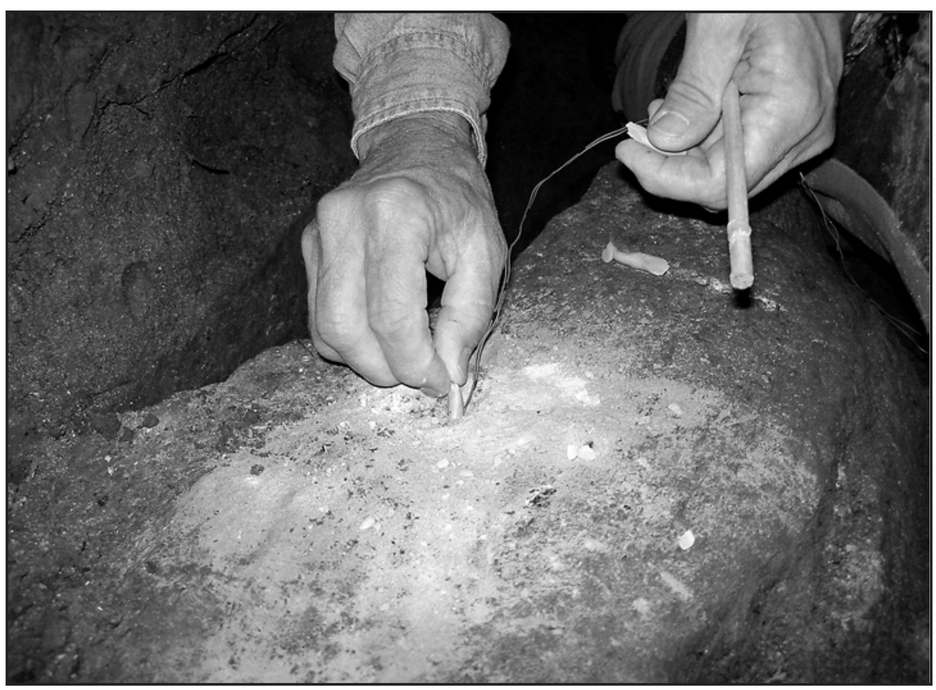

Figure 1. Rock shaving techniques using soda straws filled with pistol powder and inserted into a drilled hole in the rock create a very controlled splitting or shaving of the rock without the potential damage associated with more traditional explosives. Photo by W.K. Jones

Figure 2. An example of a cave entrance excavated using a trackhoe. This site is adjacent to an industrial park that overlies most of the cave. It will take a few years for the entrance zone area to regain a pre-dig condition, but it was felt that the benefits of gaining access to the cave for environmental monitoring and resource inventory outweighed the disturbance caused by employing heavy equipment at this far from pristine site. Photo by W.K. Jones.

Although all of these digging techniques may have a place or be appropriate at certain sites, the more invasive techniques will certainly have the greater impact on the animals living in the cave and in altering the entrance-zone environment. The digging techniques used at a site should always be the least destructive means of opening the entrance. In the case of highly protected public lands, the digging techniques must be in reasonable compliance with overall regulations on land-use at the site.

Pros and Cons of Creating a New Entrance

The most obvious benefit of digging is the discovery of previously unknown resources. This creates an increased knowledge of the geology, hydrology, and ecology of the area. This should lead to improved protection of caves due to increased awareness of the subsurface resources. We cannot protect something we don't know exists. A new entrance may also create easier and safer access to parts of the cave for environmental monitoring, resource inventorying, or possible rescues.

The creation of a new entrance will almost always cause some change in the cave environment. These changes may often be of little significance or even beneficial to certain animals living in the cave.

The potential downsides to digging include:

- Alteration of the natural appearance of the entrance or landscape
- Changes to the patterns of air circulation within the cave and the accompanying impacts to the ecosystem and mineral growth
- Cave microclimate disruption may cause an increase drying, especially during the winter
- Changes around the entrance zone may alter drainage characteristics and patterns of sediment transport within the cave
- Possible creation of an unstable passage with an increased danger of rockfall
- Potential increase in the number of visitors to the cave

These changes may occur anytime an entrance opens (or closes), whether due to natural causes or the activities of man.

The disruption of the surface area around the entrance may, at least temporarily, cause the most potential damage to the cave ecosystem. Most cave communities depend on food input coming through the entrances. Destruction of vegetation around the entrance zone may reduce cricket populations dependent on foraging in this entrance zone for food. Remediation of any surface disruption should be a standard part of any dig.

Guidelines for Diggers and Resource Managers

In most cases, the benefits of discovering previously unknown resources far outweigh the environmental costs associated with a dig. This is especially true if the digging techniques are low impact and the resulting disturbance to the entrance area is kept to a minimum. Resource managers should consider digging as an extension of field cave inventory methods if it is conducted in a way that minimizes impacts to the surface zone and passages. The digging techniques must be in harmony with overall land-use regulations for the area.

Protection and monitoring plans for the newly discovered resources should be prepared. Newly opened entrances often require some sort of cover or "lid" if the management objective is to leave the cave in the condition in which it was found. This means if the site of the dig was loose rubble and large rocks with air flowing into the cave prior to the dig, then any modification for an entrance ought to allow for air flow. Similarly, if there was no air flow and the new entrance causes air flow, the entrance ought to be arranged to stop the air flow. A pipe/culvert with a lid (Figure 3) is a time-tested technique to accomplish this and help prevent cold, dry air from altering the cave environment in the winter. In a few cases, airlocks or specialized gates may need to be installed to mitigate the effects of altered air flow. In any event, the resource manager should be able to control most of the good and/or bad effects from the newly created entrance to maintain management goals.

Cavers should plan digs for places with a good potential for success. Old, currently obstructed entrances or places where mapped cave passage is near the surface are obvious sites. Geophysical techniques may also help identify areas where cave passages are near the surface. It must be noted however, that some digs initiated at sites with little obvious potential have yielded highly significant caves such as Helictite Cave in Virginia. The digging techniques should be appropriate to the site and the surrounding area. Clean up and do reclamation work around the entrance zone after the dig is completed. In most cases, try to leave the cave in the condition in which it was found. Make certain that the excavated passages are stable and do not pose a safety hazard. Identify important resources within the cave. Photo document and plan a protection strategy for these resources (Seiser 2002). Work with the resource manager or land owner and share all discoveries promptly. In summary, dig carefully and dig softly.

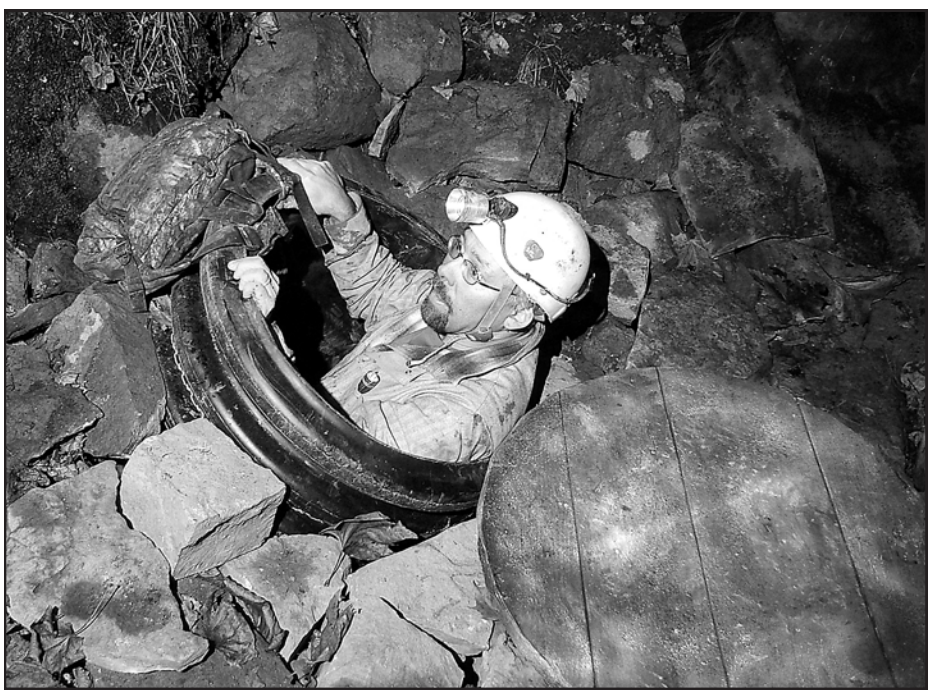

Figure 3. Dug entrances may be stabilized using culvert pipe. A lid may be fitted to control air flow and temperature fluctuations. In most cases, the management objective at the new entrance will be to maintain the cave in the same condition as before the new entrance was opened. In this example surface disturbance and visual impact are minimal. Photo by P.C. Lucas.

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VERY SMALL AND ECLECTIC CAVES: CONSERVATION AND MANAGEMENT ISSUES

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ABSTRACT

Many caves throughout the world are small and unusual, in contrast to extensive cave systems developed by karst processes. Small and eclectic caves typically go unnoticed by most cavers, speleologists, and the general public at large. However, in many cases, these caves are geologically, historically, and archeologically significant. Many are pseudokarstic and have formed by interesting genetic processes. Non-traditional caves are typically studied by individuals who are particularly fascinated with them or who live far from larger, more "exciting" caves. There are hundreds of small caves that have histories proportionally larger than their size. Small and unusual caves are often located in highly populated areas and are frequented by the local population, often by children. Many have been environmentally stressed; graffiti painted on walls and excavation and removal of materials from caves are common problems. Moreover, in some places, lesser caves may be obliterated during construction projects. The best means of protection of small and eclectic caves is through stewardship and education. Management of these features presents unique challenges, as there is often a lack of local interest in preserving them. However, if their significance is demonstrated through educational and outreach activities, local stewardship may result.

Introduction

Most caves of interest to the public at large, scientists, speleologists, and cavers are of considerable size, typically hundreds of feet to miles in length, with rooms and passages that are voluminous, or of considerable depth. In general, the larger and more extensive a cave is, the more attention it receives for exploration, study, or visitation. The literature on caves reflects this as well. There are many books, articles, and other writings that discuss superlative caves, yet there are relatively fewer accounts about the lesser caves of the world. Small caves, many of which are inconsequential in the eyes of most people, including members of the speleological community at large, rarely receive the attention that they may merit. However, in many cases, these caves are geologically, historically, and archeologically significant. Many are pseudokarstic and have formed through interesting genetic processes. There are instances where the lesser caves have been described and studied by persons who are fascinated by their attributes or their histories, either in the genesis of the caves, or with regard to human interaction over the years. It has been said that often the speleogenetic and human histories are proportionally larger that the dimensions of these caves. Small, eclectic caves are often in remote locations and thus infrequently visited. Some receive attention by cavers and speleologists only because these people live far from the larger, more traditional, and more exciting caves found in well-known karst regions.

Like larger caves and virtually all other natural features, small caves are impacted by environmental stresses, especially those induced by human activity, including economic development, construction, and poor land-use practices. These impacts lead to heightened concern about conservation and preservation of natural resources. Moreover, conservation and preservation issues naturally lead to questions of management of natural resources as a protective measure. In this grand scheme of awareness of resources, recognition of impacts that threaten them, and pro-active attention to their management, small and eclectic caves have their niche.

In order to best address the conservation and management of lesser caves, it is best to define several parameters that are applicable to the geological aspects of these landforms and to their interaction with human activity. It will then be possible to conceive of ways to promote an appreciation for them and to ensure that they will be preserved for the future.

On the Definitions of Karst, Pseudokarst, and Cave

Karst - Karst is an internationally recognized term that refers to an assemblage of landforms that have been produced primarily by the dissolution of bedrock. Chemical processes are therefore predominant and the excavation and sculpturing of rock is carried out by flowing water. The result is a sculpted and/or pitted bedrock surface on exposed bedrock or the top of bedrock that is mantled by soil. Openings in the bedrock, such as pores and fractures (namely joints or faults) have been enlarged by the dissolutional process as groundwater circulates within the rock mass. This aqueous environment leads to a myriad of landforms, including (1) caves with a wide range of length, depth, chamber dimensions, and geometric complexity, (2) springs that are typically discrete and have large discharges in comparison to those in non-karstic terranes, (3) sinkholes, natural or anthropogenic, where surficial material has been dissolutionally or mechanically conveyed into and through the karstic aquifer beneath the surface, and (4) sinking streams and blind valleys where the entire discharge from these channels enters the ground at discrete localities. Karst systems are inherently non-uniform (highly anisotropic) with spatially variable porosity and permeability. Discharge of groundwater through and from karstic aquifers is highly variable and the flow dynamics are very responsive to changes in the hydrology on the surface. Thus, changes in groundwater flow through karst are rapid as conditions of seasons and weather (particularly storms) change.

There are five requisites for the formation of karst: (1) Bedrock must be soluble in water, usually water that is mildly acidic and contains carbonic acid derived from the atmosphere or soil. Most karst forms in carbonate rock (limestone, dolostone, or marble) or in sulfate rock (gypsum), all of high solubility in natural waters. However, under the right conditions of geochemistry and climate, karst may develop in less soluble rock such as granite or quartzite that are very rich in silica. In the latter case, some interesting eclectic caves are prime examples as discussed later. (2) Bedrock must be porous and permeable. There must be openings that can accommodate the presence of water (porosity) and these must be connected in such a way that water can migrate among them and provide continuous paths of flow (permeability). In karst these openings are either pore spaces formed when sedimentary beds were laid down (primary porosity) or as fractures such as joints or faults that formed as a result of structural deformation of the bedrock at a later time (secondary porosity). (3) The water must be chemically aggressive. Pure water can dissolve rocks such as the carbonates or sulfates; however, the process is considerably enhanced where the water is mildly acidic (carbonic acid derived from carbon dioxide in the atmosphere or soil or less commonly sulfuric acid in certain localities). (4) The land surface in karst terranes must have higher and lower elevations such that water entering as recharge in the uplands will flow to points of discharge (mostly springs) in the lowlands. This topographic relief provides a hydraulic gradient that is necessary to maintain flow of water through the aquifer and the transport of dissolved material. (5) As with all geologic processes time is an important factor. The rate of formation of karst is rapid in comparison to many other geologic events, but nonetheless, the process is slow from a human perspective.

Caves and other karst features have many different geometric configurations including the sizes and orientations of passages and rooms and the overall patterns of the arrangements of these openings in three-dimensional space. There are four general factors that modify the process of dissolution as caves and karst progresses: (1) Rock layers vary in mineral composition, texture, and thickness, collectively known as the lithostratigraphy. How will a rock unit develops caves and karst depends on these conditions. Generally speaking, a bed of rock that is relatively pure in soluble content (such as calcite in the case of limestone) will develop larger or longer openings (greater caves). Conversely, relatively insoluble beds will result in caves considerably reduced in size and extent (forming some of the smaller, eclectic caves as described later). (2) Geologic structure is highly important as a modifying factor. Nearly all cavernous rocks have been deformed by stresses in the Earth's crust (tectonism). Deformation results in the tilting or folding of units of rock and produces fractures (joints and faults) that vary in size, orientation, and distribution depending on the magnitude and direction of forces during the tectonic history of an area. The size, orientation, extent, and cross-sectional appearance of cave passages and rooms are guided by the tectonic setting in place at the time of dissolutional excavation. Groundwater flow is guided along structurally deformed beds and through fractures produced by tectonics. It follows that openings (caves) enlarged by dissolving of the bedrock will likewise be guided by structure. (3) Geomorphic processes of weathering, erosion, and deposition continually modify the surface of the Earth. Accordingly the elevations of uplands and stream valleys change with time. Slopes change. Karstic cave systems typically develop at elevations governed by the position of the water table prevailing at the time. As the topographic evolves with time, water tables will respond. If the landscape is lowered by stream erosion, water tables will also be lowered as will the elevations of cave development. Typically caves in an area of stream erosion and incision that are at higher elevations are older than those that are lower in elevation. This results in the higher caves being left as relict landforms, often resulting in interesting eclectic varieties. (4) The flow of groundwater is highly variable in rate (discharge) and degree of turbulence. The depth to which groundwater circulates may vary greatly, resulting in different degrees of hydrostatic pressures. Under high pressure and steep hydraulic gradients, the chemical and physical processes of speleogenesis may be accelerated and caves of considerable depth may form.

Pseudokarst - Pseudokarst includes landforms that morphologically resemble true karst, but are produced by processes that generally do not involve the dissolution of bedrock. Pseudokarstic features can also produce sculpted or pitted landscapes. Openings such as caves are produced largely by physical or biological mechanisms as opposed to chemical processes that predominate in true karst. Pseudokarstic caves are of great variety in size and shape and may be found in vastly different geologic or geographic settings. Pseudokarstic sinkholes are produced primarily by suffosion (a geomorphic term) otherwise known as piping (an engineering term) whereby particles or grains are physically sapped and transmitted through the subsurface to be expelled elsewhere on the surface. Most pseudokarst occurs in isolated localities and these features may be largely unique. Pseudokarstic processes may or may not involve the flow of water either on the surface or in the subsurface.

Cave - The definition of the word "cave" is variable and depends on the perspective of the person using the term. To illustrate this point, the following definitions are compiled and summarized from published definitions in lay and professional glossaries and dictionaries and from established usage by the global community of cavers and speleologists and the vast literature that they have produced.

The **Dictionary Definition of cave** is based on a composite of perceptions by the lay public as written in standard dictionaries of the English language. The definition is as follows: *"A cave is a hollow space or chamber, underground, hollowed-out in the Earth or in the side of a hill, cliff, or mountain: It is produced in limestone by running water, with an opening to the surface."* Note that there is no mention that the opening must be a natural one.

The **Caver Definition of cave** is based on a composite of perceptions by cave explorers and their collective community. It may be summarized as follows: "*A cave is a natural opening in the ground that meets any or all of the following: (1) Longer than X feet or meters in length or deeper than Y feet or meters, (2) Long enough that a person can go beyond the range of being able to see daylight at the entrance, or (3) formed in carbonate or sulfate rock (limestone, dolostone, marble, gypsum, and the like.).*" Note that this definition varies greatly with respect to the geographic regions or with the mindset and interests individual cavers. Therefore the values of X and Y in the definition vary accordingly. This definition is largely tied to the degree of explorational difficulty that a cave may have for the caver; very small (short or shallow) caves provide little challenge and are often ignored as being caves. Also, this definition ignores the type of rock that is host to the cave.

The **Geologic Definition of cave** is based on a composite of definitions in published glossaries in the professional geologic literature. The definition may be paraphrased as: *"A cave is a natural underground open space, consisting of a room or a series of rooms and passages, generally with a connection to the surface and large enough for a person to enter."* Note that there is no specific requirement on the type of host rock, or on the size of the cave.

The **Academic Definition of cave** is proposed here as follows: A cave is a natural opening in the ground, in any geologic material, large enough to accommodate a human being, such that the person is totally roofed by the cave and would not be hit by a vertically falling rain. This all-inclusive definition may also be called the **"Dripline" Definition** of a cave. It includes even the smallest of such openings. It is totally unbiased, without regard to size, age, type of parent rock, geographic location, or mode of origin of the cave. Therefore this can be considered the **"Equal-Opportunity" Definition** of a cave.

Two parenthetical notes may be made regarding these definitions. First, there are numerous examples of pits, either karstic or pseudokarstic, that do not have driplines and are merely vertically walled shafts extending down from the surface. A case-by-case consideration would be needed in order to determine if these features are caves based on their depth. This certainly would be subjective. For example, one may decide in order for a vertical pit from the surface to qualify as a cave, it must be deeper than a person standing vertically at its bottom, thus completely enclosing that person except for the opening above.

Secondly, it is useful to define a "dripline." Consider vertically falling rain in the vicinity of a cave opening or overhanging cliff. The rain will hit the ground surface, but will not do so inside the entrance to the cave or beneath an overhanging rock. The line that marks the edge of the falling rain, where it is prevented from hitting the ground by overlying earth materials (typically rock), is known as the dripline. The dripline is considered the beginning of the cave. Passing the dripline and thus going underground (below the earth material) is the act of entering the cave.

What is an Eclectic Cave?

An eclectic cave is one that meets one or more of the following criteria: (1) it occurs in a geographic or geologic setting not typically associated with the occurrence of caves, (2) it has a genetic history that is atypical, highly unusual, or unique, (3) it has an unusual relationship with its surroundings, and (4) it has an interesting human history.

Aspects of eclectic caves include: (1) they are generally small with respect to length, depth, and/or volume, (2) they are often found in otherwise "caveless" areas, or far afield from more common types of caves, and (3) they are classified broadly as examples of pseudokarst; however, some are truly karstic.

Eclectic caves have been largely ignored for the following reasons: (1) they are small, (2) many are not well known and published information on them is poor or nonexistent, (3) most pose little or no challenge for exploration, (4) many require excessive time and energy to find or visit and that may be perceived to be not worth the effort, (5) They are poorly understood or appreciated, and (6) they are not considered to be caves by the caver definition.

Genetic Classification of Caves

In order to appreciate the variety of eclectic caves, it might be instructive to consider a checklist of ways that caves are formed, including both karstic and pseudokarstic examples. A brief description of each is given here:

Dissolution (Solutional) Caves - Caves formed by the dissolving of rock by slightly acidic groundwater. Most or the Earth's largest, longest, most complex, and most challenging caves are of this type. They are typically formed in carbonate rock (limestone, dolostone, or marble) or in sulfate rock (gypsum). They may be formed in relatively insoluble rock (granite, quartzite, etc.) These are true **karstic caves**. The remaining types that follow are pseudokarstic.

Volcanic Caves – Caves formed in rapidly moving (low-viscosity) lava flowing downhill from a volcano. The outer surface of lava cools and solidifies and the molten inner part continues to flow after eruption ceases, leaving behind a tube or tunnel (**lava tube**). Some may by of considerable length (up to tens of miles long), but most are much shorter. On occasion a small cave may be left behind as a mold of a biological organism (tree or animal, for example) that has been overrun by a lava flow and subsequently the remains have decayed, leaving a void. Volcanic caves are typically formed in basalt or diabase.

Littoral (Sea) Caves – Caves formed by the continuous, unrelenting crashing and abrasion of waves on a rocky coastline of an ocean, sea, or lake. They range in size from mere pockets to large openings up to a few hundred feet high or wide. They can be formed in any type of bedrock along a coastline.

Eolian (Wind) Caves – Caves formed by "sandblasting" as wind blows silt or sand against a rock cliff or steep slope. Like littoral caves, these vary in size from pockets to moderately large chambers. They seldom consist of more than a singular chamber. They form best in sandstone in arid regions. A vary of these openings are alveoli or tafoni that are found in environments that have harsh winds perhaps in association with humid air or cold, dry air.

Glacial (Ablation) Caves - Caves formed in ice by water or wind moving down slope at the base of a glacier. They consist of main passages and tributaries and may extend for thousands of feet into a glacier. Because glacial ice is continually on the move, these caves are ephemeral and are continuously being modified or destroyed. They are formed in ice, the solid state of water. Some glacial caves are deep crevasses in glaciers or interstices among jumbled ice blocks at the toe of a glacier (similar to talus caves, described below).

Suffosion (Piping) Caves - Caves formed whereby groundwater plucks small grains in a sedimentary deposit within a hillside, in a process that may be viewed as underground gullying. The process is largely mechanical and erosional in nature. Although some suffosion caves may reach several hundred feet in length, most are considerably shorter. They generally consist of a solitary passage, but they may have a branching, network pattern with tributaries. They form best in unconsolidated or loosely consolidated rocks of mixed sand and clay composition or in cases where an overlying deposit may be indurated or case hardened and less subject to collapse.

Hydroerosional (Undercut or Fluvial) Caves - Caves formed by streams that cut laterally into their banks, forming an undercut opening extending back far enough to permit human entry. This is an erosional process by running water. In rare instances, flowing glacial ice (solidified water) may create undercuts and thus caves formed in this way may be included in this category. Hydroerosional caves are usually formed in unconsolidated sediments; however, with long-term abrasion, caves may also form in consolidated bedrock.

Hydrothermal Caves – Caves formed by superheated water coming to the surface. Some openings of former geysers or geothermal springs may be enterable. They may be of any orientation, horizontal or vertical (pits). Additionally, deposits of travertine produced through precipitation from hot water often form voids as the material is deposited. If large enough to enter, they are caves. Most of these caves occur in calcareous rock such as travertine or tufa.

Fracture (Tectonic, Fissure, or Rift) Caves – Caves formed by separation of bedrock, owing to shifts in crustal rocks, such that an individual is able to get underground. Where rocks are split widely enough to allow entry. Separation of blocks may be produced by rifting as the result of tectonic activity or mass wasting, such as block gliding. Freeze-and-thaw cycles involving water in fractures may also contribute to rifting. Caves of this type consist of a fissure that is roofed over. The roof may consist of geometric ledges in the fractures or by blocks that have slid or fallen over the fissure, providing a dripline for the cave. There is some overlap in nature of these caves and those of the next two categories, rock city caves and depositional caves. Fracture caves may occur in any type of rock.

Rock City Caves – Caves formed by the separation of bedrock into a series blocks. The process involved is one of mass wasting known as block gliding. Blocks separated by fractures slide on a moderate slope, usually on another bed of rock beneath. The glided blocks form avenues among them, usually along several directions, giving the appearance of a city structure with streets (the avenues of separation) and building (the blocks); hence the name "rock city." Caves are formed if some of the avenues become roofed over (in whole or part) forming driplines. The roofs may consist of other glided blocks or talus that has fallen into the avenues. In some cases the sides of the blocks may be jagged or angular and cause overlaps or some blocks may begin to topple and lean against one another thus roofing the voids. Rock city caves may occur in any type of rock.

Depositional (Talus or Rockfall) Caves – Caves formed as openings beneath or among rocks that have fallen or toppled from a cliff or have slid or rolled down a slope, forming a jumble or pile where they come to rest. This accumulation is known as talus. The chambers formed in this way are typically no larger that the boulders that surround them. There is a wide range in length of these caves. A cave may exist under a single boulder propped on top of other rocks and perhaps have a dripline completely around the boulder and thus have no walls. Other talus caves consist of accumulations of hundreds of boulders whereby a large number of cavities may be negotiated in succession by an explorer. Caves in excess of one or two miles in accumulated length have been documented in northern New England, for example. These caves can form in any type of rock that is subject to be broken into large enough talus blocks to form cavities with driplines.

Depositional caves may also include openings that are formed in the deposition of sediments. Openings forming concomitantly with deposition are known as primary porosity. It is rare to have pores formed that are large enough to accommodate a person. The most common cave of this type is one formed by precipitation of travertine on the Earth's surface by running water at surface temperatures.

Undercutting (Shelter, Overhang) Caves – Caves formed by a rock ledge that protrudes horizontally from its base or from rocks underneath. They usually consist of a single chamber open at on or more sides and range in size from small pockets in cliffs to high and wide, overhanging cliffs. Rock under the ledge may have spalled in response to gravitational mass wasting or to frost activity. They can form in any type of rock.

Organically Produced (Biological) Caves – Caves formed largely by the active or passive presence of animals, plants, or in rare cases, lesser organisms. There are examples of openings hollowed out by animals licking sediments that contain salts to an extent that the openings become large enough to admit a human being. Elephants have licked out caves in Africa and smaller animals have similarly created some caves in Mississippi. Openings left as molds of trees or animals in lava flows (such as those found in lava terranes in the Pacific Northwest) are thus organically produced caves, even though they may also fall into the category of volcanic caves (above). Many types of rock may host organically produced caves.

A disclaimer is in order at this juncture. Organic or biologic processes, although all are chemical or physical to various degrees, are still natural. A philosophical argument can be made that all activities by human beings (who are, of course, naturally occurring organisms) are natural events. It would logically follow then, that any humanly produced underground opening in natural earth materials that is large enough for a person to enter beyond the dripline would qualify as a cave. This would include all subsurface excavations including tunnels, mines, root cellars, hollows for habitation, and others. Even though these features may be called caves in the literature (for example the Caves of Ajanta in India or the homes carved from tuff in Capadocia in Turkey, just to name two), they are not considered to be caves by persons who are geologists, cavers, or cave scientists. It is prudent to eliminate anthropogenic subterranean openings as caves, as well as other karst-like features formed by human activity (for example, sinkholes over mines or induced by pipelines) when addressing conservation and management of karst and pseudokarstic.

Uses of Caves by Mankind

People have entered caves from the beginning of humankind. Curiosity may have been the motivation for them to venture underground. However, caves have been used for a multitude of purposes by primitive peoples and by individuals in the more modern world. A compilation of activity associated with caves is presented here. Most of these uses involve small caves and in many instances the unusual circumstances under which caves are used are indeed eclectic.

Habitation - Caves have been used as dwellings from the beginning of modern mankind. Not all types of caves are conducive for living, even by the most primitive people. For example, solution caves are generally too damp for year-round shelter, but humans may have frequented them. Evidence of intermittent use includes early cave paintings, pictographs, petroglyphs, and other archeological and historical materials that are commonly found in them. Occupied caves occur in virtually all types of rock.

Prehistoric habitation of caves - Modern man and his ancestors (for example, Neanderthal man) commonly lived in the entrance areas of caves where the primary need was a roof overhead. In this situation caves, including the entrances of some very long solution caves, merely served as shelters. Some shelters were large enough to house entire communities such as villages and tribes. Others, much smaller, may have only housed a family or two. Occupation of some caves in Europe, Africa, and Asia dates back to prior to 25,000 years ago. However, in North America occupation of caves extends back only as long ago as the established peopling of the continent by migration from Asia (12,000–13,000 years ago).

Native American habitation of caves - Indians have used caves as shelters throughout North America. Many have merely camped in the overhanging entrances to large caves or in shelters of various sizes. Others have built adobe buildings within large shelters. The most elaborate cliff dwellings, such as those built by the Anasazi people, are found in many places in the southwestern United States. Many of the finest examples are preserved within the U.S. National Park System (for example, Mesa Verde National Park in Colorado).

Modern habitation of caves - Few people in modern times have lived in caves. Most of those who did were hermits, troglodytes, or anchorites. Several cave hermits are now celebrated folk figures. For example, the Leatherman wandered from cave to cave, making a 34-day circuit through New York and Connecticut in the late 1800s Additionally, woodsmen and pioneers used caves as temporary shelters for protection against the elements or as hideouts during encounters with an enemy. The legendary Daniel Boone used some caves during his treks into the wilderness.

Mining of cave deposits - In some large caves formed by dissolution, modern man has mined minerals from sedimentary deposits within the caves. These include:

Saltpetre (potassium nitrate) - Saltpetre is found within the silt and clay on the floors of many caves, in particular those that have dry sections. Saltpetre was leached from the cave dirt and mixed with sulfur and charcoal in order to produce gunpowder. This source of gunpowder was crucial in the American Revolution, the War of 1812, and the Civil War. Well-preserved examples of saltpetre-mining operations can be viewed in Mammoth Cave National Park and other caves in Kentucky and in caves of Virginia, West Virginia, Tennessee, Alabama, and Georgia.

Bat Guano - Significant accumulations of fecal droppings from bats have been mined as a source of rich fertilizer. This has been done over the years in Carlsbad Caverns National Park in New Mexico and Frio, Ney, and Bracken Bat Caves in Texas, among others.

Phosphates - Potassium phosphate has been mined and leached from cave dirt as a source of fertilizer. This is still being done at several isolated caves in Mexico, for example, despite the modern manufacture or artificial fertilizers.

Sulfates - Some Native Americans mined gypsum, mirabilite, and other sulfate deposits from caves of the central lowlands (for example in the caves of central Kentucky or southern Indiana). Scraped from walls and ceilings of passages, these minerals were used in various ways, including paints and medicines.

Caves of war - Historical records indicate that there were times during battle when caves were used as natural protection, strategic fortification, or as refuge from attacks or raids. One well-known example is the snipers' outpost, known as Devils Den, on the Gettysburg Civil War battlefield in Pennsylvania. Another is a series of caves among jumbled blocks of lava in Lava Beds National Monument in northern California used as protection during the Modoc Indian Wars.

Tourism (show caves) - Today, perhaps the most visible use of caves is as tourist attractions. Show (also known as commercial) caves are found in many states. Most are dissolutional caves in limestone, but some have formed in marble, gypsum, lava flows, sea cliffs, and talus. It is on tours through these developed show caves that most people first experience caves and learn about them. Many show caves are units of national and state park systems. Some notable national park caves are Mammoth Cave in Kentucky, Carlsbad Caverns in New Mexico, Wind and Jewel caves in South Dakota, Timpanogos Cave in Utah, Lehman Cave in Nevada, and Russell Cave in Alabama. Some caves in the United States were operated as attractions in the early to middle of the nineteenth century, including Fountain and Weirs caves (now Grand Caverns) in Virginia, Wyandotte Cave in Indiana, and Howes Cave in New York.

Entertainment - From time to time caves have been used for shows or live entertainment. There are several caves that had ballrooms or theaters, complete with wooden floors and seating, and dances with live music were held in the coolness of the cave during the hot summer months. Examples include Greenville Saltpetre Cave and Kenny Simmons Cave in West Virginia. Caves have also served as settings for motion pictures and plays.

Illegal enterprises and hideouts - Throughout modern history criminals and others breaking the law have used caves as refuges and hideouts. These are some of those uses:

> **Moonshining -** Perhaps one of the most common illicit operations in caves is the distillation of bootleg whiskey. Stills have been discovered in many backwoods caves. On occasion these operations are found to this day.
>
> **Counterfeiting -** Caves have been used as hideouts by counterfeiters. This is true of some small caves in the early settlements in New England.
>
> **Bandits -** Bandits, highwaymen, and other outlaws have used caves as hideouts from the law. Celebrated fugitives reportedly using caves include Jesse and Frank James in caves of Missouri, Sam Bass (the Ohio River Pirate) at Cave-In-Rock, Illinois, and others.
>
> **Drug production** – There have been a few modern instances where illicit production of drugs has been discovered in caves, including growing of marijuana with the aid of electric lightning.

Protection - Caves have been used as refuge from natural and man-made disasters or from inclement weather. Some people hid out in caves during Indian raids. Others braved the elements inside caves, protected from harsh blizzards and cold weather. In more recent times, such as the onset of the cold war in the 1950s and 1960s, many caves were designated as shelters against radioactive fallout from potential nuclear bomb attack. The federal government stocked some caves with bottled water and emergency food rations.

Religious sites – Some caves have served as sacred places. Archaeological evidence has supported this. Even today, this use is found at some localities (for example at the Grotto of Lourdes in France). Caves have also been used as places of worship for both primitive and modern cultures alike.

Burial sites - Although not practiced any more, burial of human remains has occurred within some caves. These are primarily Native American burials and are associated with artifacts at the site. These sites are protected by state antiquities acts and looting is outlawed.

Cold storage - As natural openings, caves were used from time to time for cold storage of perishable food in much the same way as were root cellars that were artificially dug in the ground.

Sources of water - Many cave entrances are springs, providing natural and often irreplaceable sources of water. This use of caves may be the most important and valuable. Unfortunately, clean spring water is only attainable if the recharge zones feeding water to the springs are protected from contamination.

Receptacles for refuse - Far too many caves have been used as holes for the disposal of trash and waste produced by industry, agriculture, or individual home dumping. Many caves open at the bottoms of sinkholes that were (or are) sites for dumping. Today, contamination of groundwater is a major environmental problem in karst and pseudokarst regions.

Conservation and Management Issues

As one can see from the foregoing, there is a great deal of variety in caves, especially when the pseudokarstic caves are included. Moreover, historic use of caves is highly diverse. Many of the small caves are the most eclectic, with aspects that are highly unusual or unique. Attributes of caves give them values. Caves have scientific value, historic value, archeological value, and biological value. Values are not necessarily correlative with the size of a cave.

Historically, conservation and management of cave and karst resources are relatively new pursuits that began in earnest only a few decades ago in response to increasing environmental stresses from human activity. Impetus for conservation and management has been enhanced in recent years by a growing understanding of karst processes. There is now a greater understanding of how these processes work, how sensitive karst is to changes on the land surface, and how fragile cave environments are, including delicate formations and organisms that are found in them.

The preceding listings of types of caves and how they have been used serve to illustrate the diversity and significance of smaller and "non-traditional" caves. If the speleological community and others wish to protect karst areas and caves from environmental damage or destruction, it stands to reason that small and eclectic caves should be included along with the large and more visible examples.

Small and unusual caves are often located in highly populated areas and are thereby frequented by the local population. Children often visit these caves for play or curiosity. Many small caves have been environmentally stressed. Graffiti painted on walls and excavation and removal of materials from them are common problems. Moreover, in some places, lesser caves may be obliterated during construction projects.

The best means of protection of small and eclectic caves is through stewardship and education. Management of these features presents unique challenges, as there is often a lack of local interest in preserving them. However, if their significance is demonstrated through educational and outreach activities, local stewardship may result. A small cave that has an interesting history or that serves as a natural curiosity may be visited often. Educational materials, such as brochures, booklets, video productions, and articles in local newspapers and magazines that highlight interesting stories behind these caves may provide an effective means of conserving those that have locations that are already well known and those that are already well visited. Of course, as is the case with many large caves, it may be best to keep locations of certain sensitive small and eclectic caves secret and to publish little or no information about them. This is always a case-by-case decision.

Premises to Consider in the Protection of Small and Eclectic Caves

A series of premises can serve to remind us to not exclude nor ignore the so-called "lesser" caves. The following is a list of seven concepts to consider in the conservation and management of small and eclectic caves:

- Caves form in all types of tock and in all geologic and geographic settings.
- Small caves are often the only caves found in non-traditional regions that are often regarded as "caveless."
- Small and eclectic caves may have been formed by unusual and interesting geological processes or may occur in atypical host rocks.
- In many cases, small caves have more interesting human histories than do larger caves. Some are important archeological sites.
- Small and eclectic caves may be just as sensitive, fragile, delicate, and vulnerable as are their larger counterparts.
- All caves begin as small caves. Geologically caves evolve with time and most begin small and increase with size during their genesis. This is particularly true of dissolutional caves. When caves are first explored they are small and become more extensive with continual exploration and discovery of new passages and/or chambers.
- There are no insignificant caves. However, there is a continuum of significance, with some caves being more significant or important than others.

Conclusions and Recommendations

To summarize, nearly every cave has significance and is of academic interest. It may have formed in an unusual manner or in a unique geologic or geographic setting. The more interesting and significant the cave is, the greater will be the need for its protection. Many caves, large and small, are environmentally stressed. Conservation and management strategies and practices have evolved over the last few decades. Small caves have often been overlooked. Their importance is amplified if they are the only caves in a region and are not distributed among larger more visible and recognized caves.

It has been a common practice in the compilations of cave surveys and inventories, especially those compiled by cavers on a statewide or countywide basis,

Cavers and speleologists have been compiling surveys and inventories on a statewide or countywide basis for some time. In regions that have many large caves, small caves have received little or no attention. It has been a common practice to designate small caves as "For the Record Only," abbreviated as FRO, and include them with little in the way of description and without a drawing or map. Many are not given a name and listed only as "FRO." In closing, as an appeal, it is suggested that every cave should get the attention it warrants and that the For the Record Only designation be eliminated.

Acknowledgements

I thank the many cavers who share my pleasure in searching for small caves, both in the field and in the literature, and who have a fascination with eclectic caves, with pseudokarst, and with spelean history. Many cavers have contributed to my understanding and knowledge of small and eclectic caves, including the late Robert W. Carroll, Jr., Steve Stokowski, William R. Halliday, Chuck Porter, and Cato Holler. Karen M. Kastning and our son, Kass, have accompanied me in the field when visiting and documenting many small, out-of-the-way caves in many parts of our country.

EXPERIMENTAL RESEARCH ON THE USE OF THERMOGRAPHY TO LOCATE HEAT SIGNATURES FROM CAVES

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Abstract

Thermal differences between cave entrances and the surrounding landscape have long been known. Cavers traditionally ridge walked in cave-likely temperate regions in cold mid-winter with a falling barometer in order to visually detect “fog-plumes” of escaping subterranean air from crevices and unknown earth openings in order to locate caves. We are experimenting with a high-technology solution to this cave detection method by applying infrared thermography — a useful tool in fire detection, human body location, and other building examination — remote sensing to the surface of the earth. Early trials during the spring of 2005 with a Therma CAMTM B20 HSV infrared camera, even under foliage-filled and warm atmospheric conditions, resulted in promising results in initial trials in New Mexico and West Virginia. Further research is underway at Fisher Cave, Franklin County, Missouri.

This research began by documenting temperatures of cave openings and surrounding substrates. Atmospheric ambient conditions (temperature, relative humidity, specific humidity, and dew point) were recorded inside the cave, at the entrance, and at intervals up to 183 meters. Normal images were contrasted with thermograms which showed full temperature gradients of the openings. At 118 meters, the opening could no longer be seen with the naked eye. The thermograms showed distinct images of cave openings. Trials continued to 388 meters. In excess of 300 meters, thermograms showed the distinct cave opening of Fisher Cave. At 388 meters, the thermograms showed signatures that could be that of a cave entrance. The initial results indicate that individual cave entrances have separate and unique temperature gradients. Thus, individual cave thermograms are a “fingerprint” or signature of that cave. Thermograms can be used to isolate and identify caves entrances from surrounding terrain features. Once we have established standardized procedures, thermograms may become an important tool for cave location and exploration.

This work is in the experimental stages. The evidence of its success is presented in the matched infrared/visual images which follow.

Introduction

Thermography is a type of imaging. Thermographic cameras detect in the range of the and produce images of that radiation. Since infrared radiation is emitted by all objects at ambient temperature, thermography makes it possible to "see" one's environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature, therefore thermography allows you to see variations in temperature, hence the name. With a thermographic camera warm objects stand out well against cooler backgrounds.

Thermographic technology has advanced considerably in the last few years. Several new generations have occurred, allowing us to use thermography in much broader applications. Current uses include building-energy audits, building diagnosis, medical applications, fire, military night vision, computer heat scans, industry, surveillance, and other utilitarian uses where heat production and dissipation are a factor.

We hypothesize that we can use this technology under the correct conditions to locate potential caves by photographing land masses such as hillsides and valleys while looking for heat signature changes in the images which would reveal cave openings, swallets, seeps, and other karst features.

Thermography could assist other scientific research such as geology, archeology, paleontology, bio-speleological discovery, and anthropology (such as studying the pigmentation signatures of petrocliffs) as it could assist in finding otherwise hidden openings in the earth. We believe it is currently underutilized, and are examining methods to remedy this.

Overview of Theoretic Thermography[1]

There are three methods by which heat flows from one object to another.

These are **radiation**, **convection** and **conduction**. IR viewers are primarily concerned with radiation effects, but the effects of the other two cannot be neglected.

CONDUCTION is heat movement in a solid by transferring thermal energy from molecule to molecule, heating up each adjacent area within the solid.

CONVECTION is defined as the way heat moves in a liquid or in a gas. In convection, the thermal energy uses a medium to carry it and actually develops a current in the medium to move it along more rapidly. Convection transfers heat more rapidly than conduction.

However, the most powerful effect is **RADIATION**. In radiation, electromagnetic energy is actually emitted by an object or gas.[2]

These three effects are not exclusive, but in most situations operate together towards a cumulative effect.

Contact-type heat measurement devices work by conduction. A thermometer in your mouth receives the heat energy from your body by conduction. A thermocouple attached to an instrument receives heat by conduction. All non-contact heat measurement devices use the radiation of an object to measure the temperature.

Infrared Imagers observe and measure heat without being in contact with the source and rely largely on radiation. The infrared camera used in this experiment generates a digital false-color image of the view being examined using IR sensors in the place of normal visual-range detectors.

> The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called bands, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of electromagnetic spectrum. The same basic physics usually exemplified by radio waves governs all electromagnetic waves.

The Electromagnetic Spectrum Defined[3]

Thermography makes use of the infrared spectral band. At the short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the long-wavelength end it merges with the microwave radio wavelengths.

The unit relationship between the different wavelength measurements is: 10,000 Å = 1,000

1 Sierra Pacific Innovations. http://www.x20.org/thermal 2005.

2 FLIR™ Systems Handbook for the "Therma CAM B20 HSV Camera."

3 Campbell, C. Warren. "Application of Thermography to Karst Hydrology." *Journal of Cave and Karst Studies*. 58(3); 163-167.

nm = 1 μ = 1 μm.

The Infrared Spectrum

Every animate or inanimate body that exists emits infrared energy from its surface. This energy is emitted in the form of electromagnetic waves which travel with the velocity of light through a vacuum, air, or any other conductive medium. Whenever they fall on another body, which is not transparent to the eye, they are observed and their energy is reconverted into heat. The difference between a cold or hot body is the level at which it both emits and absorbs energy. If the body absorbs more energy than it radiates, it can be considered cold. If the body tends to emit more energy than it absorbs, it is considered hot. The state of being hot or cold is a dynamic state. If a body is allowed to come to equilibrium with its surroundings, the emission and absorption will become equal and the body will be neither hot nor cold.

History of Infrared Technology

Sir William Herschel, an astronomer, discovered infrared in 1800. He built his own telescopes and was therefore very familiar with lenses and mirrors. Knowing that sunlight was made up of all the colors of the spectrum, and that it was also a source of heat, Herschel wanted to find out which color(s) were responsible for heating objects. He devised an experiment using a prism, paperboard, and thermometers with blackened bulbs where he measured the temperatures of the different colors. Herschel observed an increase in temperature as he moved the thermometer from violet to red in the rainbow created by sunlight passing through the prism. He found that the hottest temperature was actually below red light. The radiation causing this heating was not visible; Herschel termed this invisible radiation “calorific rays.” Today, we know it as infrared.

Measurement Principles

Infrared energy is emitted by all materials above 0°K. Infrared radiation is part of the electromagnetic spectrum and occupies frequencies between visible light and radio waves. The infrared part of the spectrum spans wavelengths from 0.7 micrometers to 1,000 micrometers (microns).Within this wave band, only frequencies of 0.7 microns to 20 microns are used for practical, everyday temperature measurement.

Though infrared radiation is not visible to the human eye, it is helpful to imagine it as being visible when dealing with the principles of measurement and when considering applications, because in many respects it behaves in the same way as visible light. Infrared energy travels in straight lines from the source and can be reflected and absorbed by material surfaces in its path. In the case of most solid objects which are opaque to the human eye, part of the infrared energy striking the object’s surface will be absorbed and part will be reflected. Of the energy absorbed by the object, a proportion will be re-emitted and part will be reflected internally. This will also apply to materials which are transparent to the eye, such as glass; gases; and thin, clear plastics, but in addition, some of the infrared energy will also pass through the object. These phenomena collectively contributes to what is referred to as the **emissivity** of the object or material.

Materials which do not reflect or transmit any infrared energy are know as “blackbodies” and are not known to exist naturally. However, for the purpose of theoretical calculation, a true blackbody is given a value of 1.0. The closest approximation to a blackbody emissivity of 1.0 that can be achieved in real life is an infrared-opaque, spherical cavity with a small tubular entry. The inner surface of such a sphere will have an emissivity of 0.998.

Different kinds of materials and gases have different emissivities, and will therefore emit infrared at different intensities for a given temperature.

Theoretical Basis for IR Temperature Measurement

The formulas upon which infrared temperature measurement is based are old, established, and well proven.[2]

Verbal summations of the important physics formulas are as follows:

1. ***Kirchoff’s Law:*** When an object is at thermal equilibrium, the amount of absorption will equal the amount of emission.

2. ***Stephan Boltzmann Law:*** The hotter an object becomes the more infrared energy it emits.

3. ***Wien’s Displacement Law:*** The wavelength

at which the maximum amount of energy is emitted becomes shorter as the temperature increases.

4. ***Planck's Equation:*** Describes the relationship between spectral emissivity, temperature, and radiant energy.

Thermography (infrared, thermal scans) uses specially designed infrared video or still cameras to make images (called **thermograms**) that show surface heat variations. This technology has a number of applications.

Speleology and Thermography

Speleology comes from the Greek words *spelaion*, meaning cave and *logos*, meaning study.[4] According to George W. Moore and G. Nicholas Sullivan in *Speleology: The Study of Caves:*

> Speleology is no longer a highly specialized pastime in which we are incidentally studying unusual but relatively unimportant facets of nature. As caves have been better known we have realized that they can broaden our understanding of the interaction of certain biologic and geologic processes that have been shaping our planet and its inhabitants for hundreds of millions of years. Thus, the study of caves is an important means of understanding our world.[4]

The natural meteorological conditions of temperate caves make infrared thermographic investigation possible. Differences in temperature and humidity make cave entrances discrete from the surface, and visible to thermography. As the inside of the cave maintains a constant temperature and the outside ambient temperature fluctuates with the seasons the cave entrance temperatures are normally different than the ambient outside conditions. It is this premise that this research is based on.

Moore and Sullivan put this most succinctly:

> The air in most caves is nearly saturated with water vapor — in other words, the relative humidity is close to 100 percent. This is so because seeping water moistens the ceilings, wall, and floor and that the air must pass by as it moves slowly through the cave. The constant temperature of the inner part of the cave permits this high humidity to be maintained indefinitely.
>
> Near the entrances to caves, however the humidity may be lower, partly because the outside humidity is usually lower, and partly because the cave temperature differs from the outside temperature.
>
> In the summer, warm air entering a cool cave soon becomes saturated without absorbing water from the cave walls. In the winter the air becomes warmer as it enters the cave, and for a short distance its relative humidity falls.[4]

Research assumptions:

- Finding caves and studying them is desirable.
- Cave entrance substrate temperatures are normally different from other outside substrate temperatures. The air blowing from a cave or into a cave is at a different temperature and humidity level than the outside ambient temperature and humidity.
- Cave humidity causes a different degree of moisture on the cave entrance substrates than on other surface substrates.
- An infrared camera measures and images the emitted infrared radiation from an object. The fact that radiation is a function of object surface temperature makes it possible for the camera to calculate and display this temperature.
- Cave entrances can have their surface temperatures displayed by a thermo-imaging infrared camera.

Experimental Design

Materials

The camera used for this research is the Therma CAM™ B20 HSV, which is the most sophisticated of the Infrared thermo-graphic image cameras made by the FLIR Company.

Nikon D1X Camera and lenses.

A steady tripod was necessary to get accurate signatures.

4 Sullivan, G.N. and G.W. Moore. *Speleology: The Study of Caves.* Cave Books, St. Louis, MO 1978, 150 p.

Delmhorst HT 3000 A Thermo Hygrometer and Dickson TH 550 Thermo Hygrometer to measure temperature, humidity, and dew point at cave entrances and distances from the entrance.

Data Log Recorders (HOBO-timed temp, dew point, relative humidity, and specific humidity at prescribed intervals and distances from the entrance.)

Fluke 52 II Thermometer and Thermocoupler to measure temperature readings of the substrates at cave entrances.

Methods

The radiation measured by the camera does not only depend on the temperature of the object but is also a function of the emissivity. Radiation also originates from the surroundings and is reflected in the object. The radiation from the object and the reflected radiation will also be influenced by the adsorption of the atmosphere. Our methodology was informed by the work of C. Warren Campbell.[5]

To measure temperature accurately, it is therefore necessary to compensate for the effects of a number of different radiation sources. This is done electronically and automatically by camera. The following parameters must, however, be supplied for the camera:

- The emissivity of the object
- The reflected temperature
- The distance between the object and the camera
- The relative humidity

These parameters were established for the camera with the use of handheld thermo hygrometers at the cave entrances. The data loggers were then set up to ensure accurate monitoring during the photography, and to provide data for the FLIR camera manufacturer, which is in process of establishing standard emissivity tables for limestone based on this research.

5 Campbell, C. Warren. "Application of Thermography to Karst Hydrology." *Journal of Cave and Karst Studies*. 58(3); 163-167.

Results

Measurements at the entrances of known caves for temperature, relative humidity, and dew point were taken at different distances from the entrance for the caves and locations reported in Table 1. The data was used to calibrate the B20 HSV. A tripod was required for steady images as the B20 HSV does not have a fast "shutter speed."[6]

We found that taking the thermograms was easier if the remote control was removed from the camera and used to adjust the setting and take the shots, as it helped reduced camera shake

We recorded our atmospheric readings in Table 1. The resulting thermograms and corresponding visual images are reproduced and correlated to data in Table 1 via photo caption information

We found we will need to compensate for the following conditions in future trials:

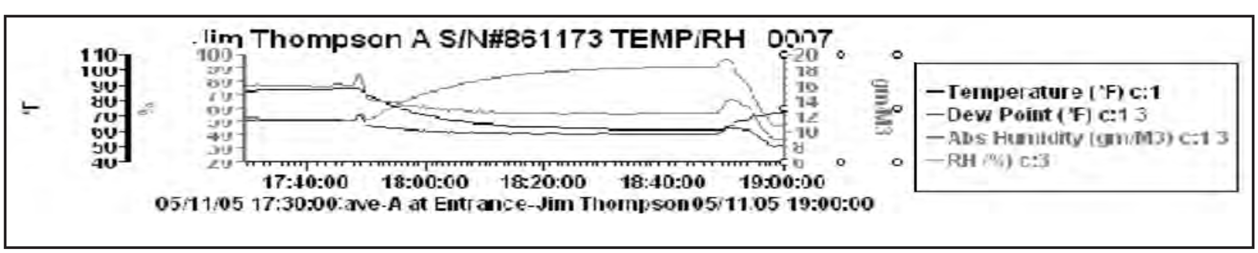
- Shooting thermograms through tree foliage will pick up reflective signatures off the leaves.
- Shadows on hills do not show the same temperature gradient as actual cave openings.
- Images without a tripod are susceptible to camera shake thereby altering the image result.

Data logger Graphs for Fisher Cave Control Location

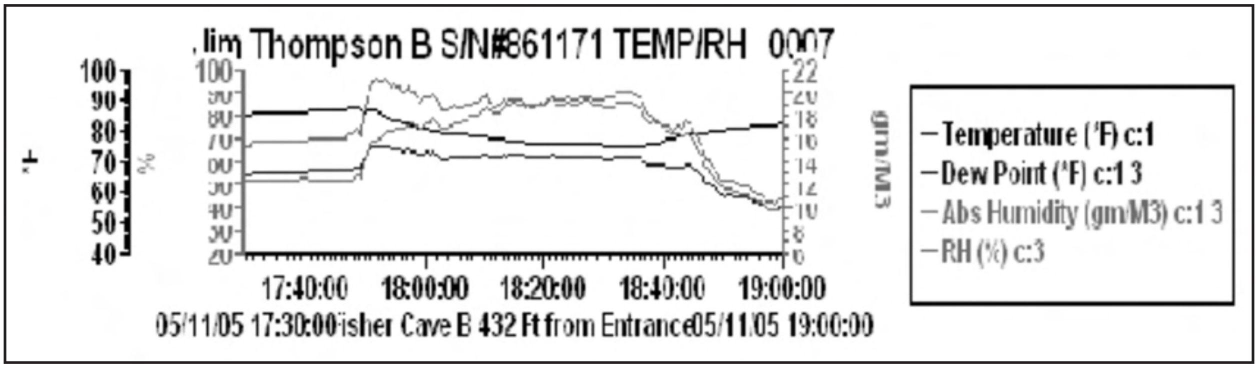
Data Log Recordings (HOBO) measuring Temperature, Dew Point, Absolute Humidity, and Relative Humidity at Fisher Cave were placed approximately 17:50 May 11, 2005, and removed near 18:50 May 11, 2005.

6 "Digital photography: the complete course." New York Institute of Photography Unit 2 Lesson Five "How to Use a Digital Camera."

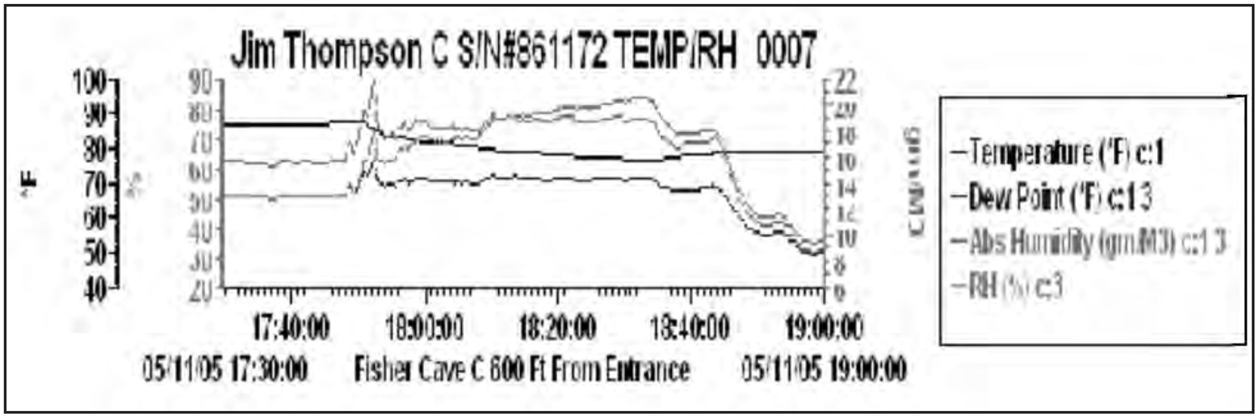
1. Data at Fisher Cave Entrance;



1. Data 432 feet (133 meters) from Fisher Cave Entrance;



1. Data 600 feet (185 meters) from Fisher Cave Entrance;

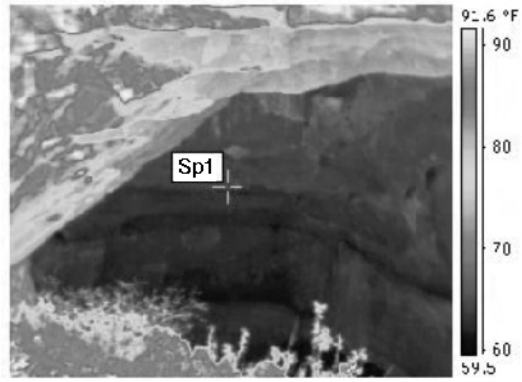


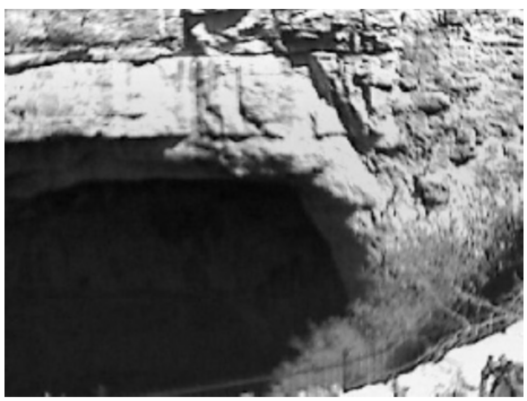
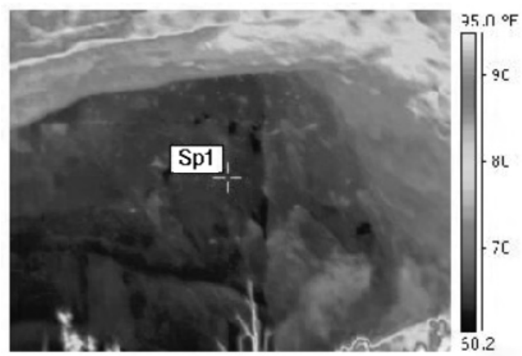
1. Table 1. Field work in support of the viability of using Thermography

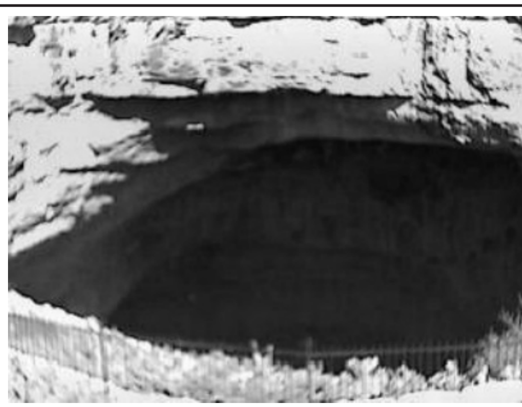
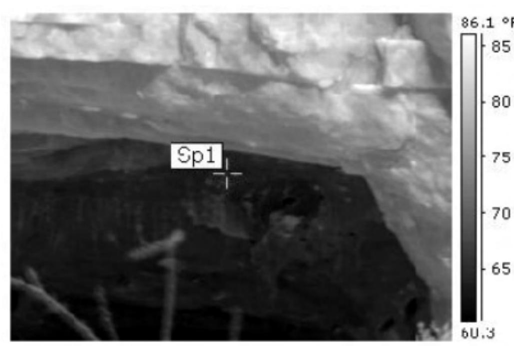
Cave and Location	Date	Ambient air temp °F and weather	Temp °F at cave entrance Humidity and Dew Point	Distance to Cave entrance in feet	Thermogram's Number (See images)
Carlsbad Caverns, N.M.	4-9-2005	90± Clear 32.2°C		±75 ft ±22.9 m	1, 2, 3, 4, 5, & 6
N038° 12.84' W091° 07.87' Hwy 185 Mo.	5-11-2005	Slight Rain 85.8°F 29.9°C RH 58.4% 69 DP°F 9.4 DP°C	Rock 75°F 23.9°C Emissitivity set .96	51 ft 15.6 m	7 & 8
Lone Hill Onyx, Mo.	4-12-2005	56.1°F 13.4°C Recent rain	52.9°F 11.6°C 92% RH 49.8 DP°F 9.4 DP°C	50 ft 15.2 m	9 & 10

Cave and Location	Date	Ambient air temp °F and weather	Temp °F at cave entrance Humidity and Dew Point	Distance to Cave entrance in feet	Thermogram's Number (See images)
Powder Mill Spring Cave, Mo.	5-13-2005	Few clouds 82.2°F 27.9°C 47.9% RH	62.8°F 17.1°C 74.1% RH Stream 56.5°F 13.6°C	222 ft 67.7 m	11 & 12
Round Spring Cavern, Mo.	5-13-2005	71.4°F 21.9°C 64.5% RH	71.2°F 21.8°C 61.4% RH	150–175 ft 45.7–53.3 m	13, 14, & 15
Fisher Cave Meramec S.P., Mo.	5-11-2005	60.1°F 15.6°C 62.4% RH 47.2 DP°F 8.3 DP°C Recent rain	61.6°F 16.4°C 66.8% RH 50.2 DP°F 10 DP°C Rock 66.5°F 19.2°C	50 ft 15.2 m	16 & 17
Fisher Cave Meramec S.P., Mo.	5-11-2005			388 ft 118.3 m	18 & 19
Fisher Cave Meramec S.P., Mo.	5-11-2005		79.5°F 26.4°C 64.6% RH 68 DP°F 20 DP°C	600 ft 182.9 m	20 & 21
Fisher Cave Meramec S.P., Mo.	5-11-2005			1,000 ft 304.8 m	22 & 23
Fisher Cave Meramec S.P., Mo.	5-11-2005			1,275 ft 388.9 m	24 & 25
Fisher Cave Meramec S.P., Mo. Hill next to Fisher Cave	5-11-2005		THIS WAS A CONTROL SHOT WITH NO CAVE-FROM SAME POINT	1,275 ft 388.6 m	26

1. Table 2. Table of Normal and Thermographic Images

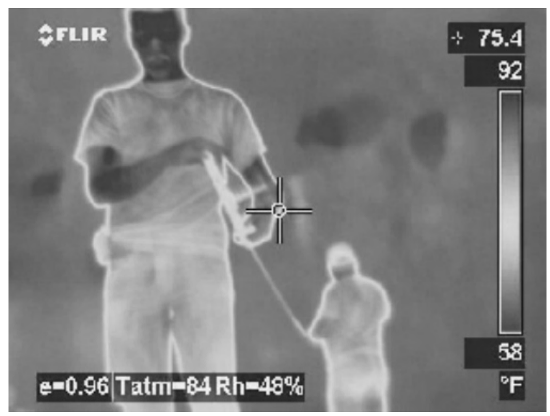
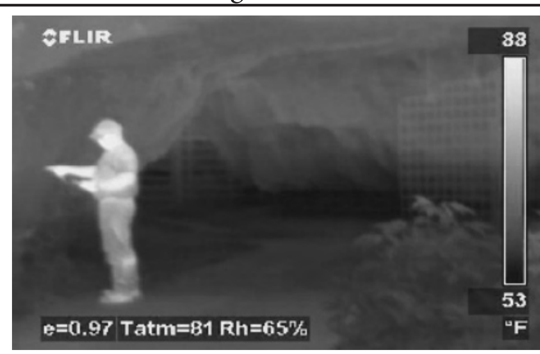
<table>
<tr><th>Number from Table #1</th><th>Normal Image</th><th>Thermogram</th></tr>
<tr><td>1 & 2</td><td>
Carlsbad Caverns, N.M. ±75 ft ±22.9 m</td><td>

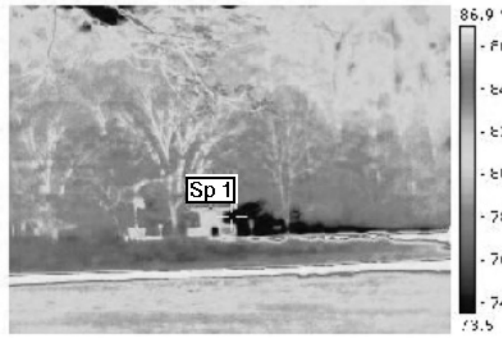
Carlsbad Caverns, N.M. ±75 ft ±22.9 m</td></tr>
<tr><td>3 & 4</td><td>
Carlsbad Caverns, N.M. ±75 ft ±22.9 m</td><td>

Carlsbad Caverns, N.M. ±75 ft ±22.9 m</td></tr>
<tr><td>5 & 6</td><td>
Carlsbad Caverns, N.M. ±75 ft ±22.9 m</td><td>

Carlsbad Caverns, N.M. ±75 ft ±22.9 m</td></tr>
</table>

Number from Table #1	Normal Image	Thermogram
7 & 8	 N38°12.84' W091°07.87' Hwy 185 Mo. 51ft 15.5 m	 N38°12.84' W091°07.87' Hwy 185 Mo. 51ft 15.5 m
9 & 10	 Lone Hill Onyx, Mo. 50 ft 15.2 m	 Lone Hill Onyx, Mo. 50 ft 15.2 m
11 & 12	 Powder Mill Spring Cave, Mo. 222 ft 67.7m	 Powder Mill Spring Cave, Mo. 222 ft 67.7m

Number from Table #1	**Normal Image**	**Thermogram**
13 & 14	 Round Spring Cavern, Mo. 150–175 ft 45-7–53.3 m	 Round Spring Cavern, Mo. 150–175 ft 45-7–53.3 m
15	This next section demonstrates the images shot at different distances from Fisher Cave, Mo.	 Measuring at cave entrance.
16 & 17	 Fisher Cave entrance, Mo. 50 ft 15.2 m	 Fisher Cave entrance, Mo. 50 ft 15.2 m

Number from Table #1	**Normal Image**	**Thermogram**
18 & 19	 Fisher Cave, Meramec SP, Mo. 388 ft 118.3 m	 Fisher Cave, Meramec SP, Mo. 388 ft 118.3 m
20 & 21	 Fisher Cave, Meramec SP, Mo. 600 ft 182.9 m	 Fisher Cave, Meramec SP, Mo. 600 ft 182.9 m
22 & 23	 Fisher Cave, Meramec SP, Mo. 1,000 ft 304.8 m	 Fisher Cave, Meramec SP, Mo. 1,000 ft 304.8 m

Number from Table #1	Normal Image	Thermogram
24 & 25	 Fisher Cave, Meramec SP, Mo. 1,275 ft 388.6 m	 Fisher Cave, Meramec SP, Mo. 1,275 ft 388.6 m

Analysis of the Results

We believe thermography shows great promise as a cave entrance location method, as evidenced by the photographs taken. It seems like a viable solution to expediting field work in locating cave sites for a variety of scientific endeavors, especially in temperate climates, where the mean annual temperature (and therefore the temperature of the cave air) is stable but local surface atmospheric conditions reflect wide seasonal variation. The ability of a thermogram to penetrate vegetative cover (once we learn to norm for reflective signatures) may turn ridge walking into a year round activity, not one confined to late fall through early spring as it is currently. The importance of recording cave entrance meteorological data as it relates to monitoring trogloxene and troglophile species is another possible application of thermographic imaging.

Research Potential

The application of using thermography can be expanded to include the discovery of unknown caves by photographing larger land mass areas such as hillsides and aerial perspectives. This paper documents fundamental field-research that was done to demonstrate that this technology is a viable tool to assist scientists from many disciplines in finding caves, sinkholes, swallets, seeps and other karst features.

As this technology continues to improve and the applications of field utilization improve, much expense and time to scientists will be saved. This field work is an ongoing project which will invariably set standards for various uses.

Thermography is currently being used in a safety research study of the heat dissipation sig-

Normal Image and Thermogram	Thermogram
 Lost World Caverns, W, Va. 120-ft rappel	 Thermogram showing effects of heat on rappel rack and rope.

Normal Image and Thermogram	Thermogram
	

natures of rappelling equipment used in speleology with a goal of finding data that can be used in establishing safer methods and equipment. See ilustrations above.

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Advice and Guidance

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Dr Malcolm Field Ph.D - Editor of *Journal of Cave and Karst Studies* Office of Research and Development. U.S. Environmental Protection Agency

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Jim Holland - Rest Con Environmental

Dave Bunnell - Editor of *NSS News*

Gregory (Tex) Yokum - who taught that caves could be located by the differences between the temperature signature at the entrance and the ambient air especially on cold days when the caves "breathed".

Thanks to Jo Schaper – Associate Editor, *Missouri Speleology*, for editing and formatting assistance.

Participation in Field Research

Barbara am Ende Ph.D - author of *Beyond The Deep: The Deadly Descent Into The World's Most Treacherous Cave*

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Justin Blankenship - Jim Thompson & Co. Inc.

Jane Fisher - Lifetime Friend, NSS and past President, Meramec Valley Grotto.

Christina Ann Thompson: Daughter and NSS member

PHOTOGRAPHY AND THE DIGITAL IMAGE WORKFLOW AS CAVE MANAGEMENT TOOLS

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Abstract

The documentation and inventory of caves is usually seen as primarily geographic data collection, which is a location and map of the cave, perhaps with some notes regarding features. This has been the most fundamental tool for planning and resource management. For the past several years the standards and accuracy of cave inventory and cartography has been steadily increasing. At the same time the quality, capability, and usefulness of photographic documentation and the use of digital database management tools has vastly improved. Many techniques for relatively low impact in cave photography have produced vast amounts of visual documentation. In many cases these materials are not utilized, or are underused, in cave management. A discussion of current, real, and potential uses of well organized, high quality image database is presented. Some ideas for standards and methods for organizing and incorporating digital image management are explored. The uses for a visual archive of cave resources is really only limited by imagination and of course the interest and enthusiasm of those involved. At present, there is an unprecedented volunteer base of motivated photographers working in caves. The prudent management of this volunteer resource is also a logical and important tool. The nature and format of visual documentation is also a very fast evolving area. The nature of the cave, the setting, and the management goals should be reflected in choices of methods, materials, formats, archiving, and the standards for both the photographs and photographers.

CORRELATING GEOPHYSICS AND CAVE CARTOGRAPHY FOR GREATER ACCURACY AND APPLICATION

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Abstract

The accuracy of cave cartography will inherently be compromised due to factors associated with cave survey. A few of the more common of these error producing factors include but are not limited to: subsurface conditions causing errors; magnetic drift created from head lamps, lighting products, and other electromagnetic emitting devices; and survey instrument miscalibration. These errors are usually slight, but as the length of the cave increases, so does the cumulative effects of these errors.

The paper demonstrates how the correlation of geophysics and geographical information systems can be combined to detect and eliminate these errors for a significantly higher level of accuracy when drafting surface to subsurface cartographic representations of a project area. The paper also demonstrates these techniques for improving this accuracy through a variety of means. Initially, a brief description of subsurface survey techniques and associated errors are discussed. Geophysical equipment and data interpretation techniques for the respective equipment are examined. Geophysical equipment discussed includes microgravity, electrical resistivity, cave radio, and others. Next, methods for integrating this geophysical data into GIS programs including ArcGIS 9 are shown. Finally, multiple case studies are presented to demonstrate how these techniques are being used for better surface to subsurface cartographic correlation.

ASSESSMENT OF ATRAZINE WITHIN A KARST LANDSCAPE IN ROUGH RIVER LAKE RESERVOIR, KENTUCKY

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Abstract:

Atrazine, a herbicide used in the production of no-till corn, is a growing concern to the quality of drinking water for many rural water suppliers. Western Kentucky University's Hoffman Environmental Research Institute along with Kentucky Department of Agriculture and the University of Kentucky's Cooperative Extension Service were awarded a grant by the United States Environmental Protection Agency to do an assessment of atrazine levels in the Rough River Lake watershed (Kentucky) which encompasses 142 square kilometers. The Rough River Lake reservoir has four water treatment plants that are responsible for serving three counties with their water needs. Roughly 90 percent of the landscape of Rough River is composed of karst, with numerous sinkholes, caves, and sinking streams. One water treatment plant, Hardin County Number One, gets its entire water supply from two major springs, both with a combined drainage area of 48 square kilometers. Grab and stratified samples were collected from 18 locations within the study area. Sampling rounds were conducted on a 14-day cycle during the growing season and 28-day cycle during the fall and winter months. Results showed that five locations had over 3 parts per billion, the Environment Protection Agency's maximum contamination level for atrazine, for at least two sampling rounds. Two sites, Highway 259 and Walters Creek, recorded levels over 10 parts per billion. Sampling will continue through 2006 in the Rough River Watershed.

HOW ARE WE DOING? EVALUATION OF CAVE AND KARST PROGRAMS.

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Abstract

A routine of evaluation and assessment of program success is a critical aspect of knowing if you have achieved your objectives, where to focus further attention and resources, and of demonstrating your success to administration and granting agencies. Evaluation may be in the form of a satisfaction survey with questions ranking responses using a Likert-scale, open-ended questions, or gap analyses. Gap analysis evaluates the gap between what your constituents want your program to achieve and how they perceive your program is succeeding. Focus groups provide another format for evaluation that is flexible and interactive. A formal external review includes preparation of a critical self-study, review of documents by an external review team, an on-site visit, and a final report. An external review of the National Cave and Karst Research Institute was conducted in 2004.

Introduction

Why should we be concerned with evaluation? Evaluation is a form of assessment, and assessment allows us to know if we have achieved our goals and objectives. We can determine if we are putting enough resources into critical areas for more effective use of scarce resources. Evaluation also gives useful information for supervisors, accrediting and granting agencies, and other decision-makers who impact a program.

There are many different ways to evaluate programs; we will focus on four types of evaluations: 1. Satisfaction surveys, 2. Gap analysis (also known as importance-performance surveys), 3. Focus groups, and 4. External reviews.

Evaluation often falls under the regulations of the Department of Health and Human Services for the use of Human Subjects if your organization receives any federal, and often, state, funding. Nearly all evaluations you are likely to conduct will fall under the category of exempt research, particularly if subject anonymity is maintained, but the researcher is not allowed to determine if their own project is exempt or not. All Federal and Academic institutions have Internal Review Boards that evaluate proposals involving the use of human subjects. Be sure your evaluation, no matter how simple, has approval before you begin.

Satisfaction Surveys

Satisfaction surveys are the simplest type of evaluation. It's everywhere these days. Usually they are used to determine the effectiveness of a discrete program or event. Examples include instructor and course evaluation, service where they change your oil, or satisfaction at a conference. You have certainly seen the advertising campaign used by Geico insurance, where they proudly claim that 97% of their customers are satisfied that their claim service is fast and fair.

Most satisfaction surveys use a five-point Likert scale, where you are given a simple statement to evaluate. The most difficult choice to state is the middle one. You want it to be truly in the middle and not just a neutral or not applicable choice. An additional category can be added for not applicable.

5 = strongly agree
4 = agree
3 = undecided
2 = disagree
1 = strongly disagree
(NA = not applicable)

In the Geico example, the 97% customer satisfaction is the number of respondents in the top two categories (highly satisfied and satisfied).

A five-point scale can also be used to gather specific information, for example:

Select the number of caves you visit per year:

5 = more than 20
4 = 15 to 19
3 = 10 to 14
2 = 5 to 9
1 = 0 to 4

Or for simple choices:
1 = yes
2 = no

Gap Analysis

A gap analysis evaluates the gap or the space between where we are and where we want to be. This style of survey is often described as an importance-performance evaluation. You may be familiar with the United States Geological Survey Gap Analysis Program that is often used in State Comprehensive Wildlife Management Programs. (See http://biology.usgs.gov/cbi/ or http://www.gap.uidaho.edu/) The focus of this program is to keep common species common. The program attempts to identify common species and plant communities and to determine if they are adequately represented in existing protected areas at the local, regional, state, or national level. The Gap Analysis helps to identify priority areas for conservation.

A gap analysis is often part of a satisfaction survey. In the Geico example, one question would be: "Geico is fast to process my claim." The next question would be: "Fast processing of claims is important to me." Each question has the five-point Likert response choices. You can determine the gap between importance and satisfaction by simple subtraction. One of the most important applications of a gap analysis is to make important decisions about effective use of resources. The data can also be plotted as shown in Figure 1. The actual quadrant boundaries can be shifted as appropriate: in this example the boundaries are simply set in the middle of both scales. Note that the points fall into one of four areas. The area marked Well Done indicates projects of increasing importance that are being done well and need to be maintained. Low Priority Items are not being done well, but your constituents don't care. Items falling into the Less Attention area are being done well, but are not valued. The Needs Attention quadrant is the most important one. These items are very important to your constituency, but they are not satisfied with the job you are doing. Often resources can be shifted from Less Attention or Low Priority areas.

Survey Design

Get whatever assistance you can before you begin. (For a good review on survey design, see Schuett *et al.*, 2000.) Stay focused on what you want to know. Let your overall goal or question guide you in writing the questions. You want to keep the survey brief; generally no more than 15–20 questions. Keep your questions neutral, short, and direct, with no more than one item per question. For example, Geico would have to ask a question about speed of processing claims and a different question about the fairness of claims. To ask if claims service is both fast and fair in one question will not get you the information you want. Perhaps clients are satisfied with the fairness but think the service is too slow. Having two answers for one question is not possible. Make sure your categories of responses make sense, especially the middle one. (As a bad example, a recently received survey asked for frequency of participation but choices of yes or no.)

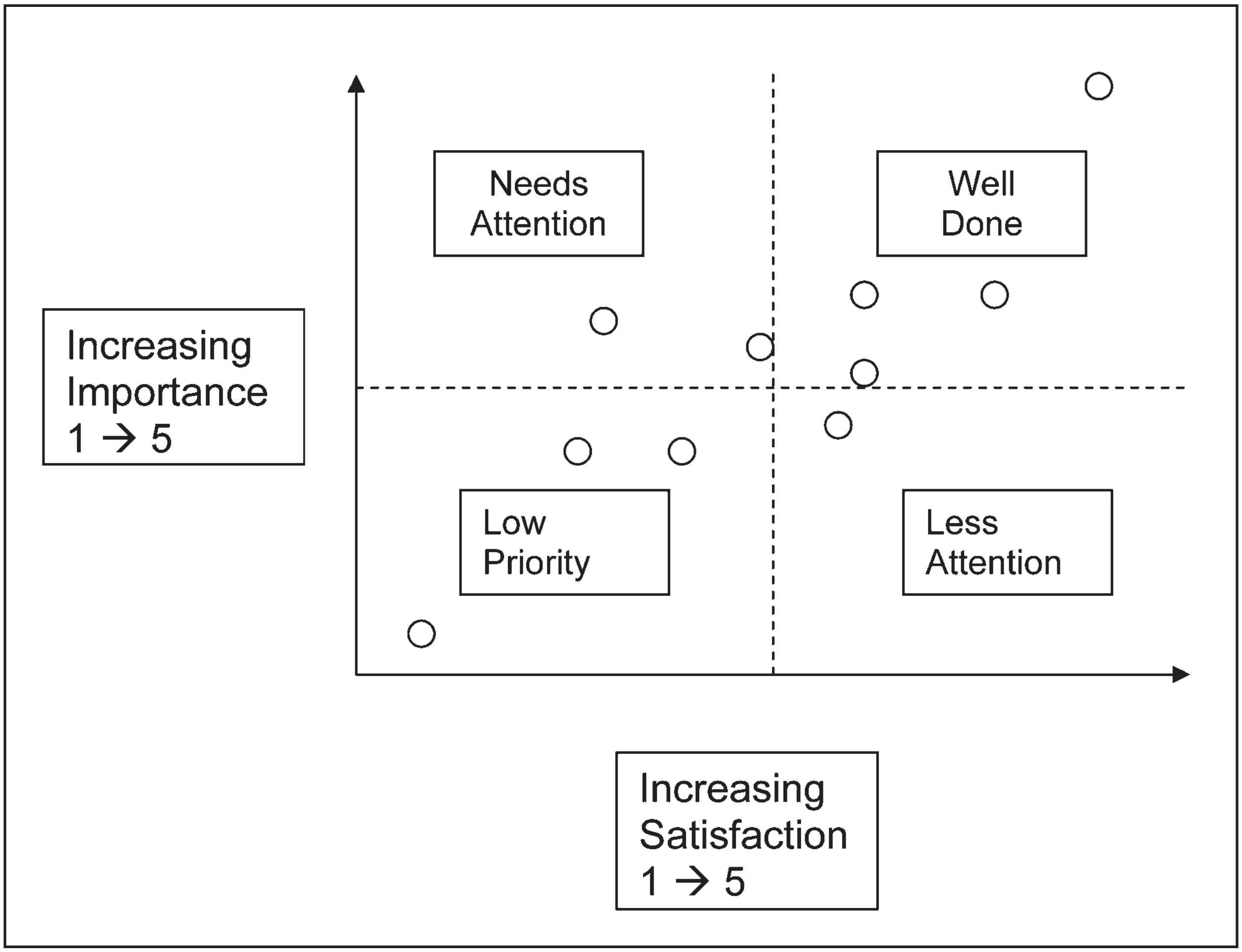

Figure 1. The gap between importance and satisfaction, and the amount of attention each item needs.

How will you conduct the survey? A paper form? Will it be passed out to participants or mailed? Will you do a Web survey, as the NSS recently did of its membership? Should you telephone? There are software programs available that make survey design very simple, but success still depends on good questions.

The actual survey should have a title. Appearance is important, so you want to leave space and not cram questions together. Include clear instructions for taking the survey and how/when/where to return the completed survey. Provide a self-addresses, stamped envelope for a written survey. You can (optional) include a brief (no more than one page) cover letter that explains why you are asking for their opinion, the purpose of the survey, and why it is important. If appropriate, ensure confidentiality by reporting only results from the survey as a whole, and not by individual responders. Be sure the survey is approved by your Human Subjects committee, if applicable.

If possible, pilot the survey using a focus group. A recently received survey asked to rank a service using a scale of 1 to 5, but they neglected to define if 1 or 5 was good. In this case, a grading scale of A–E would have been a better scale choice. Use the focus group to find out if the client understands the instructions and the purposes of the survey. How much time does it actually take to complete the survey? Are there any questions the client does not understand, or interprets in a manner that was not intended? Are there any inadvertently offensive questions or terms? Do people understand how, when, and where to return the survey? Can you actually code the data you get for entry and analysis? Will you actually use all the information (if not, eliminate the question). Should you include space for open-ended comments?

You will need to identify all costs of survey design, printing, administration, return, and analysis.

Finally, be sure that all individuals who work with the target audience for the survey are knowledgeable about your program and can appropriately answer questions that may arise during the process.

Administering the Survey

One very important factor with any survey is the response rate. While there are no set standards, you want the best possible rate of return. You can increase your response rate by on-site, in-person interviews or surveys. You can also send mail or e-mail reminders that stress how important it is for the client to participate. You can also increase your response rate by conducting the survey over the telephone, but that approach will greatly increase your cost and risks making an unwanted intrusion upon your constituents time and home. If you use e-mail you will end up with faster responses and longer open-ended responses, but you will also have a lower response rate (Seguin *et al*., 2004).

Focus Groups

While a focus group can help with piloting surveys, they can also be a useful means of conducting a survey (Krueger and Casey 2000). The biggest limitation to a focus group is a small sampler size. The greatest benefit of focus groups is that they are interactive. Some telephone surveys can be interactive if you allow for multiple tracks of questions depending on a particular response. In an interactive survey, the clients will tell you what they want, and you have the flexibility of following up on an interesting discussion thread. Focus groups require a lot of planning and a clear objective. Whom will you invite and how? Where will it be held? Who will facilitate the discussion? How will you record the discussion? How will you translate the results from the focus group into action? Focus groups may require expert help to plan and conduct.

External Review Process

External reviews are widely used to bring in outside experts who can look at your program or department and help you determine effectiveness, solve problems, suggest changes, and help set goals. A typical external review may involve four phases: the preparatory phase, the development of the self-study, the site visit, and a response and wrap-up session. External reviews are often done using a five to seven year cycle.

Goals of the External Program Review Process:

- To provide a comprehensive assessment of the current status of the
- Examine stakeholder and potential stakeholder attitudes and opinions on issues related to the unit.
- Develop recommendations to allow the unit to build on existing strengths, maximize opportunities for growth, and solve current problems.

Guiding principles for program review:

- Candid assessment of strengths and weaknesses that can lead to program improvement
- Provide a framework for excellence within the mission and goals.
- Facilitate short-term and long-term strategic planning.
- Account for use of resources and level of support among constituencies.
- The review must be broadly participatory.

Case Study

We will discuss a program review process developed for the National Cave and Karst Research Institute. The Institute is still in the very early stages of development, but it is important to establish procedures for evaluating success of programs and the Institute itself. The recommended procedures were used in a streamlined external review conducted in August 2004 by Lavoie.

The U.S. Congress established the Institute through the National Cave and Karst Research Act of 1998 (S.231), which directed the National Park Service to establish the Institute in Carlsbad, New Mexico (NCKRI 1998). The Institute's legislative purposes are:

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

At the time of the review, the National Park

Service directly managed the Institute and the designated academic partner, New Mexico Institute of Mining and Technology (New Mexico Tech), managed parallel applied and academic cave and karst programs. The City of Carlsbad constituted a third primary partner who will build the headquarters building and has secured much of the non-federal matching funds that support the National Cave and Karst Research Institute effort.

The review process had four phases:

Phase I. Preparatory. The responsible individual notifies the Institute that they are due for an external review. The self-study team is appointed, and external reviewers are selected. One external reviewer will be appointed by each of the principle partners: The National Park Service, the city administrators of Carlsbad, New Mexico, and New Mexico Tech.

Phase II. Self-study. The Self-Study Report is an interpretive document that uses data as much as possible to assess current program status and future directions. Data should be analyzed and discussed in relation to the Institute's mission and goals. Although the report is compiled and written by the self-study committee, the Director of the Institute is responsible for the content, accuracy, and completeness of the work. While there are many possible formats, the reviewer (Lavoie) recommend a "Progress, Plans, Problems" approach that reviews Progress since the last review, discusses Plans for the next three to five years, and candidly describes known Problems. It is important that the self-study be clear and objective. The tone needs to be positive (avoid whining). The report should also be realistic. Yes, we could all achieve more if we had twice as much staff and money, but you need to be optimistic yet realistic in setting your expectations.

Phase III. Site Visit and Report. The actual review includes a site visit by the external reviewers. The final review should include information and recommendations from structured and open-ended questions. Establish a firm deadline for completion of the report. In the case of the 2004 National Cave and Karst Research Institute review, Lavoie visited the Institute offices in Carlsbad, met with Carlsbad city officials, met with National Park Service personnel at Carlsbad Caverns National Park, traveled to New Mexico Tech, and interviewed several individuals by telephone.

Phase IV. Response. Once the final report is received it needs to be reviewed by all of the principle partners. Each needs the opportunity to respond to the report, and offer additional information that can be added to the report. The self-study team should meet to discuss the report. In the 2004 National Cave and Karst Research Institute review, principle contacts for each of the three primary partners (National Park Service, City of Carlsbad, and New Mexico Tech) received copies of both the Institute review and the proposed methodology for future program reviews as the Institute evolves. The National Park Service forwarded the report to the Associate Director of the Natural Resource Stewardship and Science with the recommendation that they be shared with other National Park Service science and education programs considering external reviews.

2004 National Cave and Karst Research Institute Review: Selected Findings and Recommendations

We will report on selected findings and recommendations. In summer 2004, the Institute was still in the very early stages of formation. The next review will be much more useful, and will use three reviewers rather than just one person.

Mission Statement:

The National Cave and Karst Research Institute facilitates speleological research, enhances public education, and promotes environmentally sound cave and karst management.

As you can see from the Mission Statement, the Institute has clear objectives. Yet upon further review of documents relating to the Institute and the self-study, Lavoie found three objectives in the Mission Statement, six goals, five core values, and six services that they promised to offer. There is considerable overlap, but it is important to stay focused on a manageable number of issues. If you say you will do something, then your success needs to be assessed, so keep it to a manageable number, typically no more than five to seven.

One problem that was identified going into the review was negative relations with several individuals dating from the time of the transition from an interim director to a full-time director. Many of the individuals were contacted and agreed to work with the Institute on projects of significance.

Several recommendations dealt with the relationship of the Institute to the National Park Service, which has indirect oversight of its activities, and the Institute's relationships with the other principle partners, New Mexico Tech and the City of Carlsbad. These relationships were clarified over the following year through a Cooperative Agreement and several task assignments between the National Park Service and New Mexico Tech, a community workshop convened by New Mexico Tech that led to the establishment of an Interim Board of Directors, and extensive discussion between the National Park Service and the City concerning building design. New Mexico Tech can provide assistance with grant writing, fundraising, and personnel.

Construction of the new Institute facility in Carlsbad is obviously a top priority. Since the review, the project has been delayed several times, and construction is now planned to begin in early 2006 (the construction bid period is open through October 2005). At the time of the building dedication, the Institute needs to try to change the congressionally mandated limits on fundraising that they must match federal funds 1:1 from non-federal sources. Since most of the Institute's activities in research and education are in areas where the largest single funding source is the federal government, this restriction places an excessive burden on fundraising.

An area of increasing importance to consumers is Web presence. While the National Cave and Karst Research Institute has a good Web presence, the Cave and Karst program at New Mexico Tech did not. The program also did not have a formal curriculum after two years. (A Google search string (cave and karst education) follow-up run in October 2005 still does not mention the New Mexico Tech program in the first 20 hits.)

Lavoie also made a series of minor recommendations. The Institute hosts a popular speaker series at Carlsbad, and Lavoie recommended taking the speaker series on the road. The Institute would publicize available speakers to appropriate educational and professional agencies, and might even defray some of the costs. The Institute should develop a small financial assistance program to organizations and to individuals working in areas of importance to cave and karst, although there are some technical issues that limit awarding grants. Lastly, Lavoie recommended expanding developing partnerships by making it possible for individuals to formally associate with the Institute through a program of associates.

Conclusion

The types of program reviews presented here can be used to evaluate a wide range of individual activities, programs, or entire organizations. Evaluation allows you to assess the success of programs in meeting your goals. For more information on the National Cave and Karst Research Institute, go to http://www2.nature.nps.gov/nckri/

Acknowledgement

The National Cave and Karst Research Institute provided funding for development of the review process and the external review conducted by Lavoie in August 2004.

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2007 NCKMS, SAINT LOUIS, MISSOURI

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Abstract

With over 6,000 known caves, Missouri is a major karst state with many ongoing cave and karst studies and land management activities. The 2007 National Cave and Karst Management Symposium will be co-hosted by the Missouri Department of Conservation and the Missouri Caves and Karst Conservancy. We will present information and photos of the meeting place, Powder Valley Nature Center, Kirkwood, in the greater Saint Louis area. There will be an emphasis on hydrology and biology, but plenty of other information too. We are starting to plan sessions and field trips now. Powder Valley is an educational facility with a fine auditorium and meeting rooms, which the Missouri Department or Conservation will offer at no charge to the symposium. Arrangements are being made with a nearby hotel, where we have hosted other conferences.We plan to host a free, evening, public event at Powder Valley to pull in interested cavers, landowners, show cave operators, and the public to hear a panel of interesting speakers. I invite all who are interested to come to this presentation and comment on what you would like to see and experience at the 2007 National Cave and Karst Management Symposium.

STRATEGIES FOR ACCESSING AND MONITORING HIGH-FLOW, SUBMERGED CAVE SYSTEMS IN CENTRAL FLORIDA

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Abstract

Ecosystems of underwater caves often receive little study, due to the fact that they are not amenable to ordinary environmental sampling techniques and protocols. While many cave systems in north Florida are well-studied, and their biodiversity well-documented, the submerged caves in central Florida are not well understood due to the narrow conduits and the high-flow associated with these systems. Technical divers from the Cambrian Foundation, a 501c3, based in Orlando, Florida, have recently developed several new approaches for collecting data in these systems which are impenetrable to recreational divers. Developing techniques for reliably sampling these habitats is challenging, and must consider issues such as sample container buoyancy, sterile technique, confined space, gear configuration (that is, no-mount diving), and working in a submerged cave environment, as well as the safety issues and conservation practices that are important in this type of field work. In addition, we will address the importance of landowner/agency/researcher relations and access to these difficult systems. The goal of this presentation is to share these strategies with others working in similar systems that are difficult to access. Development of these procedures is particularly important as it has permitted us to develop long-term monitoring programs to study these habitats, which have often been neglected due to logistical constraints.

THE GLOBAL KARST DIGITAL PORTAL: AN EMERGING COLLABORATORIUM WILL ENHANCE INFORMATION EXCHANGE AMONG CAVE AND KARST MANAGERS

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Abstract

The National Cave and Karst Research Institute, the University of South Florida, and the University of New Mexico are developing an on-line portal to enhance information access and improve communication within the national and international karst community. The partnership will develop an on-line portal housed at the three institutions and provide free access to a variety of information including journal articles, images, maps, datasets, bibliographies, and gray literature. This holistic undertaking seeks to bring karst research and management forward in the digital age. In addition, the project will create global connections by creating Institutional Repositories in countries with active karst research programs. These Institutional Repositoriess will be linked to the portal and will provide a user-generated submission process for enhancing the diversity of materials available through the portal. We are currently transforming *A Guide to Speleological Literature of the English Language 1794-1996* into the portal's first searchable on-line product. In the future, thematic areas, such as cave sediments, conduit flow models, best practices for management, established restoration techniques, geoengineering, geomicrobiology, and speleothem records of climate change, are among many topics to be included in the portal. A key component of this project is the gathering of lesser-known materials, such as masters' theses, technical reports, agency file reports, maps, images, databases, and newsletters. We seek input from the karst community as to what materials are most critical to bring on-line at the outset of the project and on the identification of significant repositories of karst digital data and information. The U.S. Congress has charged the National Cave and Karst Research Institute to centralize and standardize speleological information and to promote national and international cooperation. The international community has expressed a desire for greater information coordination and global accessibility. Thus, this project responds to disciplinary needs by integrating individual scientists into a global network through the karst information portal.

Introduction

Karst science is coming of age and is of growing significance to our global population. Approximately 20% of the earth's land surface is karst and ~40% of the world's populations get their drinking water from karst aquifers. Thus, karst science has expanded in recent decades from a subdiscipline of geology and geography to a major interdisciplinary area that brings together teams of researchers and educators from the physical, natural, and social sciences. Due to the geographic extent of karst landscapes, researchers from numerous countries actively investigate karst science. Although significant to the global karst community, the results of much of this research are difficult to obtain. Likewise, given the local significance of karst, such as in areas like the Edwards Aquifer basin of central Texas and the Floridian Aquifer, research is often reported in the gray literature or exists electronically in the form of data files or maps. The best collections of karst literature are private, limiting general access to these materials.

A team of karst scientists, educators, and librarians from the University of South Florida, University of New Mexico, and the National Cave and Karst Research Institute came together in spring 2005 to build a partnership between themselves and other members of the karst community to address these needs through a Karst Information Portal. The mission of the project is to transform global understanding of karst terrains through an innovative, on-line linkage among karst researchers, educators, and land managers who desire a wide variety of electronic information on karst topics (Figure 1).

Goals of the Karst Information Portal

The goals of the Karst Information Portal project are to foster:

1. communication among karst scientists, and,
2. accessibility of the results of karst research projects globally.

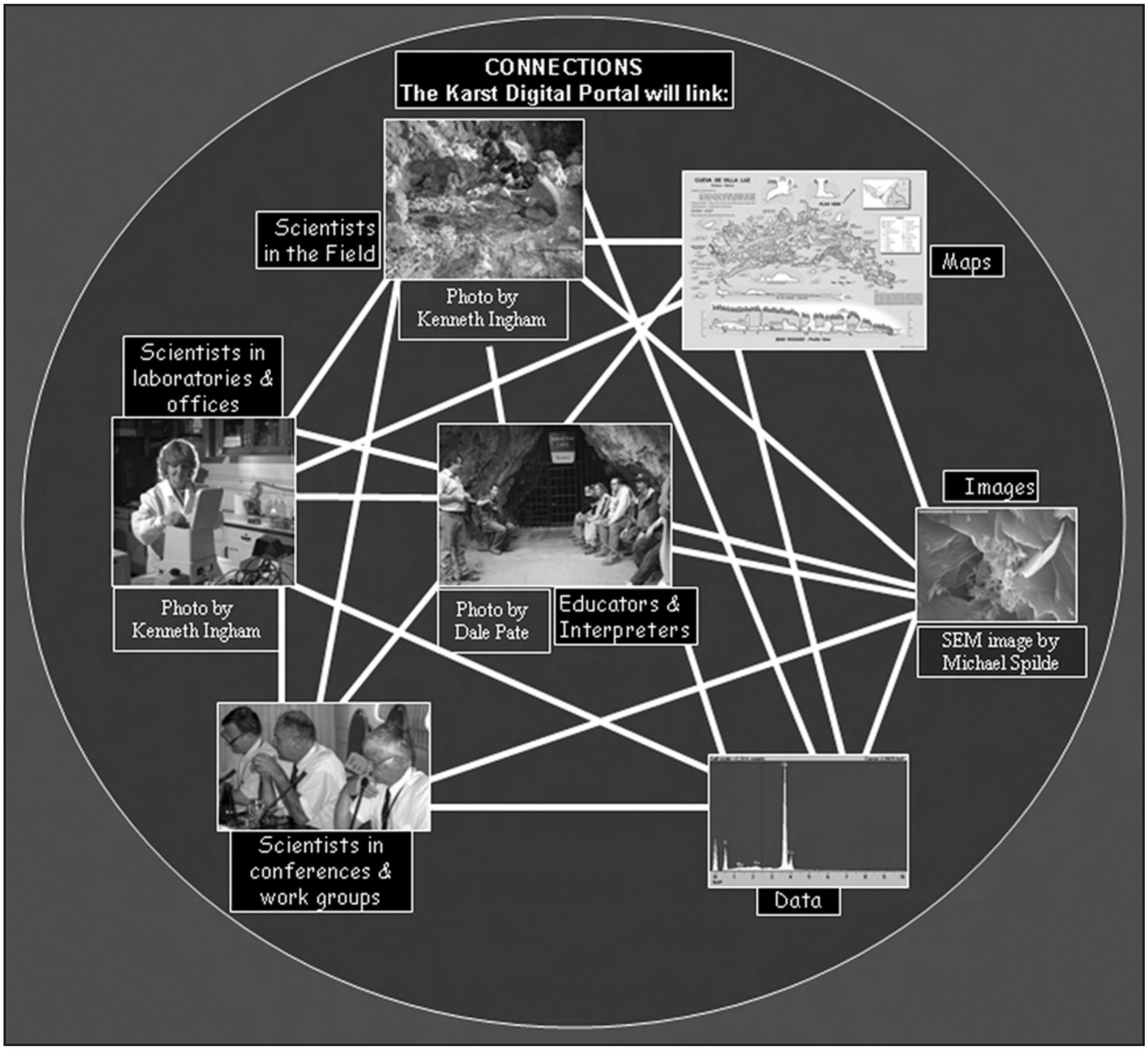
Specific ideas for Karst Information Portal include to:

- Create innovative linking between repositories of digital objects;
- Increase access to karst literature and resources, many of which are:
  - grey literature;
  - in non-English languages;
  - poorly indexed;
  - inaccessible;
- Provide searchable digital versions of key karst resources;
- Create a searchable version of *A Guide to Speleological Literature*;
- Establish Open Archive Initiatives through the fostering of Institutional Repositories at key karst centers worldwide.

The partners

Diana Northup, a Professor Emerita in the University Libraries, a Visiting Associate Professor in the Biology Department and an active karst researcher, instigated the University of New Mexico effort. Her team includes several members of the library faculty and staff who are already involved in innovative digitization and portal efforts, such as SORA (digitization of key ornithology journals), a Dspace institutional repository of University of New Mexico scholarly output, and Harvester for Creating Knowledge Streams in the Americas, which brings together social science and medical content and metadata for an Open Archive Initiative covering North and South American publications.

The Karst Research Group at the University of



South Florida houses one of the largest concentrations of karst researchers in the country. Consisting of nine faculty from four departments (Geology, Geography, Environmental Science, and Biology), the group conducts research on a variety of topics including karst geomorphology, hydrology, climate change, and karst policy. The group offers Ph.D. and masters opportunities in all participating departments. Ten graduate students are currently mentored by faculty in the program. Members of the Karst Research Group, in partnership with the University of South Florida's Patel Center for Global Solutions and the University of South Florida Library, make up the University of South Florida team working on the karst portal. The Patel Center's Mission is to develop a body of knowledge that is used to promote sustainable economic development and reduce poverty, improve the quality of the natural environment, human health, and security, and foster an understanding of diversity of cultures and arts. The support of the Patel Center provides a global focus to the portal project.

The U.S. Congress charged the National Cave and Karst Research Institute to centralize and standardize speleological information and to promote national and international cooperation. The University of New Mexico team initially asked the National Cave and Karst Research Institute to join their effort, recognizing the need to build a broader community effort. University of South Florida was independently developing a similar effort and, through the National Cave and Karst Research Institute, learned of the University of New Mexico initiative. the National Cave and Karst Research Institute arranged a meeting between Len Vacher of University of South Florida and members of the University of New Mexico team in May 2005, and the triad partnership was established.

Current status of the project

Staff, faculty, and graduate students from the three partners identified the development of a karst information portal as a main objective of our joint efforts. Current plans focus on a karst information portal hosted at the University of South Florida, the University of New Mexico, and the National Cave and Karst Research Institute. The portal is envisioned to provide free access to a variety of information including journal articles, images, maps, datasets, bibliographies, and gray literature. In addition, the project will create global connections establishing global Institutional Repositories (institutional repositoriess) that include a user-generated submission process for enhancing the diversity of materials available through the portal. Karst Information Portal's first entry will be a transformed *A Guide to Speleological Literature of the English Language 1794–1996* as a searchable on-line database of the references included in the *Guide*. Access to this information has been graciously granted by the original publisher, Cave Books.

A second project is the creation of a global repository of scanning electron images and spectra from karst and cave investigations. Scanning electron micrographs from geomicrobiological and mineralogical investigations in caves represent a major data management problem and a major opportunity for increasing linkages among karst scientists. Much new morphological data is being discovered in these images and the Karst Information Portal represents an ideal means of fostering collaborations in interpreting these morphological data.

In the future, thematic areas, such as cave sediments, conduit flow models, best practices for management, established restoration techniques, geoengineering, geomicrobiology, and speleothem records of climate change, are among the many topics contemplated for inclusion in the portal. A key component of this project is the gathering of lesser-known materials, such as masters' theses, technical reports, agency file reports, maps, images, and newsletters.

January 2006 Workshop

The partners seek input from the karst community as to what materials are most critical to bring on-line at the outset of the project and on the identification of significant repositories of karst digital data and information. To this end, an international panel of karst and mega-cyber information specialists, consisting of researchers, educators, land managers, and information technology specialists, will gather in Carlsbad, New Mexico, in mid-January 2006. The workshop will:

- Identify needs that may be met through a karst digital portal;
- Identify resources that might be enhanced through a karst digital portal;
- Seek ideas as to how best to structure a karst digital portal;
- Learn from experienced leaders in mega-cyber efforts;
- Explore opportunities to collaborate with existing mega-cyber efforts;
- Develop a planning document from the workshop that will guide efforts over the next several years in the development of the karst information portal;
- Provide an opportunity for interaction among international leaders in karst science and experts in mega-cyber efforts to develop linkages for future collaborative efforts.

The resulting planning document will be posted on the the National Cave and Karst Research Institute Web site and widely distributed.

Summary

This holistic undertaking seeks to bring karst research and management forward in the digital age. Besides being a source of karst research results and references, linkages will foster communication among karst scientists, educators, and land managers, many of whom are widely scattered and unknown to each other. This portal will help to usher in a new era of karst research and education that is focused on global understanding of karst science. The international community has expressed a desire for greater information coordination and global accessibility. Thus, this project responds to disciplinary needs by integrating individual karst workers into a global network through the karst information portal.

Biographies

Hose is the National Park Service's Director of the the National Cave and Karst Research Institute and an adjunct professor of earth and environmental sciences at the New Mexico Institute of Mining and Technology.

Brinkmann is a karst geomorphologist and public policy specialist and professor in the Department of Geography at the University of South Florida.

Northup is a Professor Emerita in the Science and Engineering Library and a Visiting Associate professor of Biology at the University of New Mexico.

USING SANDBLASTING TO REMOVE GRAFFITI IN BLOOMINGTON CAVE, UTAH

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Abstract

Kyle Voyles and Jon Jasper have long considered how the appreciation of Bloomington Cave outside of St. George, Utah, would change if all of the graffiti and trash was removed. Our thinking was if we could get the community involved in restoring the cave, then interest and appreciation would increase to allow long-term maintenance and management of the cave.

During the winter and into spring of 2005, seven weekends were spent removing the graffiti covering the walls of Bloomington Cave. The project, headed by Kyle Voyles (Parashant National Monument and St. George Bureau of Land Management) used Ray Keeler's sandblasting equipment and other techniques to thoroughly remove graffiti throughout the main trails of the cave. The project was a great success due to the efforts of 48 volunteers from Utah, Arizona, Nevada, and California. Now that the project is completed, the Bureau of Land Management is looking into writing and implementing a comprehensive Cave Management Plan.

This presentation includes an eight-minute video documenting the project and the methods. You will be able to see the equipment in action sandblasting away the graffiti

Executive Summary

Between January and April 2005, 48 volunteers worked seven weekends sandblasting off the graffiti in Bloomington Cave outside of St. George, Utah. This monstrous effort was able to remove graffiti from the main visitation areas and has greatly increased attention and appreciation of the cave. Due to show of effort the St. George Bureau of Land Management is writing a cave management plan which is considering an information kiosk, improved parking, bathroom facilities, and possible gating. The project began as a huge restoration effort and is quickly becoming catalyst for the long-term management of the cave.

Brandon Kowallis picks up garage in a room full of graffiti.

Doug Powell with full safety equipment

Description of Bloomington Cave

Bloomington Cave is an awesome maze of passages formed along a 60 degree dipping fault. It is presently mapped to 1.3 miles in length, the fifth longest cave in Utah. Being a short drive from the city of St. George in southern Utah, the cave is quickly growing in popularity.

Problems Arise

In the 1950s, in response to the unmanaged increase in visitation, the local Dixie Grotto blasted the entrances shut to protect to the cave and its visitors — twice. The entrances were dug open and the visitation continued to rise. Today, the cave's visitation is 644 visitors/year, that's 1.8 visitors/day. However, the visitation is not the only problem.

Most of the visitors to Bloomington Cave are vastly unprepared. Most are equipped with only one, possibly head mounted, light, no backups, no helmets, improper clothing, gym shoes, and no previous caving experience. To keep from getting lost in the labyrinth of passageways, visitor's routes have been marked with graffiti and miles of string. Over the years, the lack of any management and visitor education has greatly deteriorated the cave.

The cave's Big Room has a high-angle drop of about 150 feet. Many tales have been told of folks sliding out of control to its bottom. In the summer of 2002, a Boy Scout was rescued after taking this fall and breaking his leg. Later the same year, on Christmas Eve, a 17-year-old girl accidentally backed off the ledge called the Boardwalk where the cave's register is found. She rolled through a small opening and down through the Big Room to the bottom of the cave. She became the cave's first fatality.

This fatality marked a need for change — a need to improve public education of proper cave safety and a need to restore the esthetic and recreational value of Bloomington Cave. The removal

Kyle Voyles setting up to sandblast graffiti of the graffiti throughout the main part of cave was just the first step.

Sandblasting 101

To remove any significant amount of the graffiti in Bloomington Cave is a massive undertaking. Kyle Voyles reserved the use of Ray Keeler's sandblasting equipment as the primary method to remove the graffiti. For seven weekends, volunteers converged on Bloomington Cave to sandblast off the many tags from the walls and ceilings.

Setting up of the sandblasting equipment in itself is an amazing feat. High-pressure hose and electric cords need to be run from the air compressor and generator on the surface to be split to the three sandblasting guns removing graffiti in the cave.

Safety is a high concern for all of the volunteers. Diving goggles and respirators are worn to protect the workers from the sandblasting media that blasted everywhere as the graffiti is being removed. Many drops had to be worked around for the thorough removal of the graffiti. Safety lines were rigged to prevent injuries from falls. The sandblasting equipment and 5-gallon buckets of media beads were rappelled to the bottom reaches of the cave.

Keeping the project going took great effort combating weather, recruiting of volunteers, and maintaining equipment, as well as the cost of acquiring sandblasting media. The project started just after a large flood hit St. George. The flood was large enough that FEMA arrived to help. Several bridges were washed out. The route we successfully used took us four hours of digging to finally reach the cave.

A large number of volunteers were needed to keep such a large project moving forward. Oddly, the majority of the volunteers traveled more than four hours to reach Bloomington Cave. Matched with the great amount of snow and rain, some weekends were extremely lean with only three or four people showing up.

The project came with many costs. Amazingly, cavers contributed approximate 90% of the project's total cost. The equipment, such as the air compressor, generator, miles of hose and electrical cords, lights, and repairs, were an estimated donation of $65,000. The volunteers donated over 1,000 hours or an estimated value of $18,000. In the end, the total project costs are estimated at $85,000.

The main consumed expense was the sandblasting media. Even being able to recover and use about half of the media, 40 buckets were needed at $55 per bucket, that's over $2,000 in sandblasting media alone. This cost was covered by the funding received by the St. George Bureau of Land Management Office, Kolob Care and Rehab, Color Country Grotto, and Outdoor Outlet.

With all things said, the sandblasting was extremely effective in the removing the graffiti.

What's next?

What's next? The seven weekends were only enough to be able to remove the graffiti from the main trail from South Entrance to the bottom of the Big Room. Much graffiti still exist the northern part of the cave, so future efforts are being considered.

Before and after photos of graffiti removal

Currently a management plan is being written to outline the future management actions for the cave. Routes through the cave are planned to increase the cave's appreciation while minimizing the need for marking the cave with miles of string and graffiti. These routes are to be marked with different colored, numbered reflectors to mark the different routes. A kiosk is being designed to include a detailed cave map showing marked routes and information on proper caving and conservation techniques to educate visitors. A gate is being considered to eliminate undesired "party" visitation. The plan may also include delineated parking, installing restrooms, and improvements to the cave trails. This project is great example of how volunteer restoration projects can create needed management change.

DOWN UNDER! INCORPORATING CAVE AND KARST RESEARCH INTO PRIMARY AND SECONDARY EDUCATION

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Abstract

Join the Cambrian Foundation team as we highlight two of our recent research expeditions in the underwater caves of central Florida and the Yucatan Peninsula. This presentation/poster is a *must* for teachers, parents, and students alike. The Cambrian Foundation, a 501(c)(3), based in Orlando, Florida, is dedicated to research, education, preservation, and exploration of the aquatic realm. Specifically, we specialize in research and technical diving, gathering data for scientists in places where they cannot go. In addition to research and as our mission statement indicates, our other passion is education — for only when someone understands something will he or she then learn to protect it; therefore, education equals preservation. This presentation will highlight Cambrian Foundation research expeditions where youth of all ages (elementary through college-age) are incorporated and integrated into an actual field research expedition. You will see students exploring the Florida aquifer via a human ROV (remotely operated vehicle), surveying an unexplored cave in the middle of the Mexican jungle using underwater cave survey techniques, dealing with the challenges of hauling gear and equipment over difficult terrain, producing a map for a landowner in the Yucatan, and learning firsthand about the geology, ecology, and biology in the world beneath their feet. As the students have learned, cave research — especially in remote areas — is challenging, but collecting data crucial to protecting these endangered habitats is priceless.

The Cambrian Foundation was founded in 1994 upon the premise that research, education, preservation, and exploration of aquatic habitats will help maintain these ecosystems for future generations. The Cambrian Foundation, a not-for-profit 501(c)(3) corporation, has served the public and scientific communities in many ways. As specialists in deep, mixed-gas technical diving, our expertise lies in collecting data from environments where people cannot typically go. We are actively involved in surveying and mapping underwater cave systems, documenting new cave species, and monitoring water quality in many endangered subterranean systems from central Florida to the Yucatan Peninsula and Bermuda. These data are then used to provide information to scientists about the health of our aquifer, the hydrogeological features of submerged ecosystems, and the pathways and patterns of groundwater flow.

In addition to research, our other passion is education. Each research expedition always has several educational components to it, whether it means visiting school and community groups, creating daily updates on our Web site that highlight our expedition experiences, or having young people join us in research, we are committed to sharing with others about the importance of caring for our delicate groundwater systems. Our staff is composed of microbial ecologists, marine ecologists, ocean acoustic engineers, marine geologists, aqueous geochemists, professional educators, environmental scientists, environmental filmmakers, and biospeleologists. The two cave conservation education projects featured at the 2005 National Cave and Karst Management Symposium in Albany, New York, highlighted the Central Florida Karst Project, and the Sistema Camilo, Akumal, Mexico expeditions.

The Cambrian Foundation has been working in the Wekiwa Springs and Apopka Blue cave systems as part of the Central Florida Karst Project since 1999, and as such, has done a number of outreach and hands-on educational events related to the research within this cave system. Since 1999, our educational outreach program has reached over 150,000 people ranging from conference attendees at the annual meetings of the Boston Sea Rovers, National Association of Cave Diving, National Speleological Society, American Geophysical Union, to Rotary and Kiwanis Clubs, to various primary and secondary school classrooms, and major research universities. Research in the Wekiwa and Apopka Blue Systems is always a highlight of these presentations as it is such a unique environment (diverse microbial colonies, difficult access to the cave, high flow system, presence of fossil remnants, newly documented species of stygobitic macrofauna, proximity to urbanization and development, and the like). Approximately 450 young people have been educated in the field using the caves of central Florida as experiential learning opportunities. Details regarding the dates and locations of these presentations can be found on the Cambrian Foundation Web site (http://www.cambrianfoundation.org) under the Events Calendar.

In addition to providing free, educational outreach programs to schools and community groups that request our presentations, we also provide the means by which young people can learn about these systems in a hands-on learning style. During this project, students learned firsthand about the world beneath their feet by using a research diver with surface communications gear as a human-remotely operated vehicle, or human-ROV. In this way, the young people were able to communicate directly with a researcher in the underwater cave systems and to experience this extreme underwater environment from the safety of land above. This human-ROV lets young people learn kinesthetically via live video and audio feed to the surface about the geology, ecology, and hydrology of the underwater cave environments. It also affords them the opportunity to explore a place few people have ever been.

Certainly the most unique thing that the Cambrian Foundation does is to allow and encourage students of all ages to not only participate, but to be incorporated onto our research expeditions. Participating in expeditions and field programs enables young people and their teachers to experience a real-world working research expedition as they are integrated onto the Cambrian Foundation team as research assistants. This helps them to understand the importance of protecting these delicate interconnected aquatic systems while at the same time actually *experiencing* what it is like to work in a particular profession within the broad field of environmental science. For the past four years, students from the Fuqua School in Farmville, Virginia, have joined us on a variety of expeditions ranging from underwater archaeology off the east coast of Florida to cave survey and exploration in the jungles of the Yucatan Peninsula.

Sistema Camilo, currently the 14th longest surveyed underwater cave system in the world, lies near the village of Akumal, Mexico, approximately 70 miles south of Cancun. Students participating on this international research expedition were exposed to a variety of new scientific, cultural, and historical settings in which their learning took place. The goals of the educational portion of this expedition were threefold: First, by incorporating high school students into a working field expedition, we provided an unparalleled opportunity for hands-on experiential learning. Second, we focused on teaching the local population about the importance of water protection, conservation, and proper use by talking with several landowners in the area and sharing what we have learned in the previous years through our research. Third, by having our students update the Web site on a daily basis, they educated people throughout the world about the serious issues facing this and other cave systems.

Prior to their arrival in Mexico, students began learning about the terrestrial and aquatic biodiversity unique to this part of the Yucatan. Once the expedition began, students were immersed in applied algebra, geometry, biology, oceanography, hydrogeology, and Mayan culture. Each day began by assisting the research dive team in mixing gas, preparing cylinders, logging pre- and post-dive information, assembling gear, and launching divers in the remote cenotes that connect this underwater labyrinth. Since the students were not certified cave divers, we provided them with an analog activity to understand what challenges the research divers face while working in this environment. Fortunately, the Cambrian Foundation's reputation among landowners in the Akumal area has afforded us a unique opportunity to let our young research assistants survey and map a cave on private property that, according to the landowner, had never been explored. In order to appreciate the difficulties faced by divers trying to collect data in these systems, communication during the survey was limited to hand signals and messages written on slates. Our team of ten students worked for five days to explore and survey the lines they laid in this cave system, eventually producing a map for the landowner. In addition to mastering the tasks of compass navigation, running reels, GPS navigation through the jungle, and nonverbal communication, the students also collected water quality data, both in their cave and in the cenotes of Sistema Camilo, critical to understanding how these caves are capable of supporting such a unique assemblage of species in an environment devoid of sunlight. These data also helped illustrate what happens during speleogenesis, especially in submerged karst systems where a halocline is present. They were also tasked with the responsibility to explore the surrounding jungle in search of new recharge areas and karst features that supply this watershed.

This expedition was documented by Genesis Productions in a documentary produced for *Virginia Currents*, a PBS series based in Richmond, Virginia. We are very grateful to our staff and supporters who make these expeditions possible, and who take the time to educate young people today about the importance of appreciating and caring for their environment. Fuqua School, a small private school in south central Virginia, is to be commended for their continued participation and support in letting students learn outside the classroom. Lessons learned on these and other Cambrian Foundation projects will hopefully inspire young people to protect and care for the delicate resources our planet has to offer.

Author biographies:

Amy L. Giannotti, President of the Cambrian Foundation, graduated from the University of Virginia in 1999 with a masters degree in environmental science/aquatic ecology. Since then, Amy has spent the last several years instructing on both the high school and college levels, developing curricula for environmental science programs, and encouraging students and teachers to participate in research expeditions. Amy was the first teacher to bring her students on a Cambrian Foundation expedition back in 2002, and after that rewarding experience, she left the teaching profession to focus on experiential field learning opportunities for people of all ages.

Terrence N. Tysall is the Chairman of the Board for the Cambrian Foundation. He has an undergraduate degree in environmental science, and he is currently enrolled at Texas A&M University pursuing a masters degree in biospeleology under the direction of Dr Tom Iliffe. His thesis research will focus on the biodiversity of anchialine caves in Bermuda. Terrence has over 30 years of diving experience in every underwater environment the planet has to offer and is an advisor to many scientific and technical diving research organizations. As the founder and past president of the Cambrian Foundation, he is inspired by the opportunity to teach young people in outdoor classrooms in various corners of the world.

Dr Rima B. Franklin, a microbial ecologist, is a graduate of the University of Virginia's environmental sciences program. She earned her PhD in 2004 and is presently completing her postdoctoral fellowship at NASA's Kennedy Space Center Life Sciences Laboratory. Rima serves as an advisor to the Cambrian Foundation, and she is the principal investigator on several projects studying the importance of microbial communities in food web structure of submerged cave systems.

MONITORING AND ENVIRONMENTAL MICROCLIMATE DATA OBTAINED FROM STUDIES OF HIBERNACULA SITES WITHIN CAVES IN WEST VIRGINIA

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Abstract

Extreme Endeavors and Consulting was contracted to perform environmental monitoring of hibernacula sites of endangered species of bats in Hellhole and Schoolhouse Caves which are located in Pendleton County, West Virginia. A system was exclusively developed by Extreme Endeavors to operate inside of a cave, extracting the most precise temperature and air pressure data ever seen from an underground environment, while providing the ability to correlate with a similar monitoring station located in the proximity of the entrance of the cave. The monitors within this system remained tethered to the surface, where autonomous power systems provided power and a connection to a communications link, allowing data to be downloaded throughout the year, simply by dialing over a modem.

A feature was designed for this system that allowed the user to set the sample rate of data from 1 minute to 24 hours. The sample rate of each module was set to a fine-scale time interval, a finer scale resolution than previously utilized in measurements taken from these caves. This resolution and extremely precise data has shown various anomalies that are occurring in this micro environment. The data from these caves will be presented, along with extensive computations that show the correlation of surface data to the data from within the cave. Details will be presented to show how mathematical analysis can be used to tell us more information about the world below.

An additional result of our study is the product of component failure causing us to perform further research into the surface potentials created around sink holes and caves. Data from this investigation will be presented and an analysis of our findings will be scrutinized.

Background

Extreme Endeavors is currently under contract to provide environmental monitoring of Hellhole and Schoolhouse Caves, two important bat caves located near a local limestone quarry. These two caves are very well known throughout the U.S. and abroad and have challenging vertical drops, difficult passageways, and Hellhole is amazingly vast and complex. The caves are home to approximately 200,000 bats of seven species, including significant concentrations of two federally endangered bats, the Virginia big-eared bat and the Indiana bat.

To ensure the safety of these animals and to protect their environment from any changes that might be created by the nearby quarry, yet maintain the economic benefit that the mine brings to the local economy, a complex, intricate, and sensitive monitoring system has been installed to keep a vigil eye on conditions at important bat hibernation sites in these two caves. This monitoring system is more precise than ever seen before in a cave and overcomes the multitude of problems associated with placing sensitive electronics inside of a cave. The system measures temperature inside the caves with an absolute accuracy of 0.2° F and a relative accuracy (and precision) of 0.05° F. Absolute pressure is measured with a static accuracy better than 0.002 PSI. Data can be recorded at a user-selected interval between 1 minute and 24 hours; when recording data every 15 minutes, the system can record data for over five months before the memory fills up.

Extreme Endeavors and Consulting is a small firm located in Philippi, West Virginia, with experience in taking technology to the harshest and most desolate environments found on earth. This experience in harsh environments includes several operations Extreme Endeavors and Consulting has been involved in throughout Antarctica and working with the U.S. Military in taking technology from the war fighter and integrating it for use with emergency service workers.

One requirement for monitoring Hellhole and Schoolhouse caves was that the data had to be remotely accessible 24 hours a day and 7 days a week. Remote data access to one of the most rural and remote regions of West Virginia was much simpler than providing NASA access to the middle of Antarctica in the middle of winter, but it was soon discovered that other problems would be encountered. This remote access was a tremendous leap forward in underground monitoring systems. It provided the ability for the users to initiate specific monitoring requests, such as altering the frequency of readings or making queries on specific monitoring areas, without having to enter the cave (which would disturb the bats in hibernation).

On a regular basis, the systems can be connected to and data can be downloaded to a computer for evaluation and analysis. The systems within the two caves each have multiple sensors capturing temperature and barometric pressure data. By utilizing this data, it is easy to remotely assess if the cave environments are tracking the outside environment appropriately. Any significant change in temperature and/or barometric pressure would point to a possible breach of the cave's environment; creating a new cave entrance could dramatically alter airflow in the cave and change the ambient temperature. Regular monitoring allows for a timely response in protecting the endangered animals' environment in the event of an accidental breach of the cave.

The cable used to achieve this communication consists of three twisted-pair, 24-gauge lines in a watertight jacket that is encased in steel/aluminum conduit. One twisted pair delivers power from the surface module to the in-cave modules, the other two twisted pairs are used for a full duplex RS-485 communication network. Each module is controlled with a microcontroller containing an embedded operating system which allows us to communicate with each module individually and issue various commands according to a custom protocol.

This project was brought to the attention of Mr Tom Minnich from the Robert C. Byrd Institute of Advanced Flexible Manufacturing. This organization provided assistance in operations and in development of the packaging required for the severe environment found underground. The Institute provided the machining assistance in the fabrication of these environmentally sound, intricate packages to go into some of the most diverse conditions imaginable. Currently Mr Minnich and Extreme Endeavors are working together to promote sensor and technology transfer from NASA Langley to add different capabilities into the realm of underground monitoring.

Results

One of the problems associated with running a remote data access system, specifically for the first time ever, is that it is sometimes not possible to account for all of the operating and environmental conditions the system will be subjected to in the initial design. This was discovered when

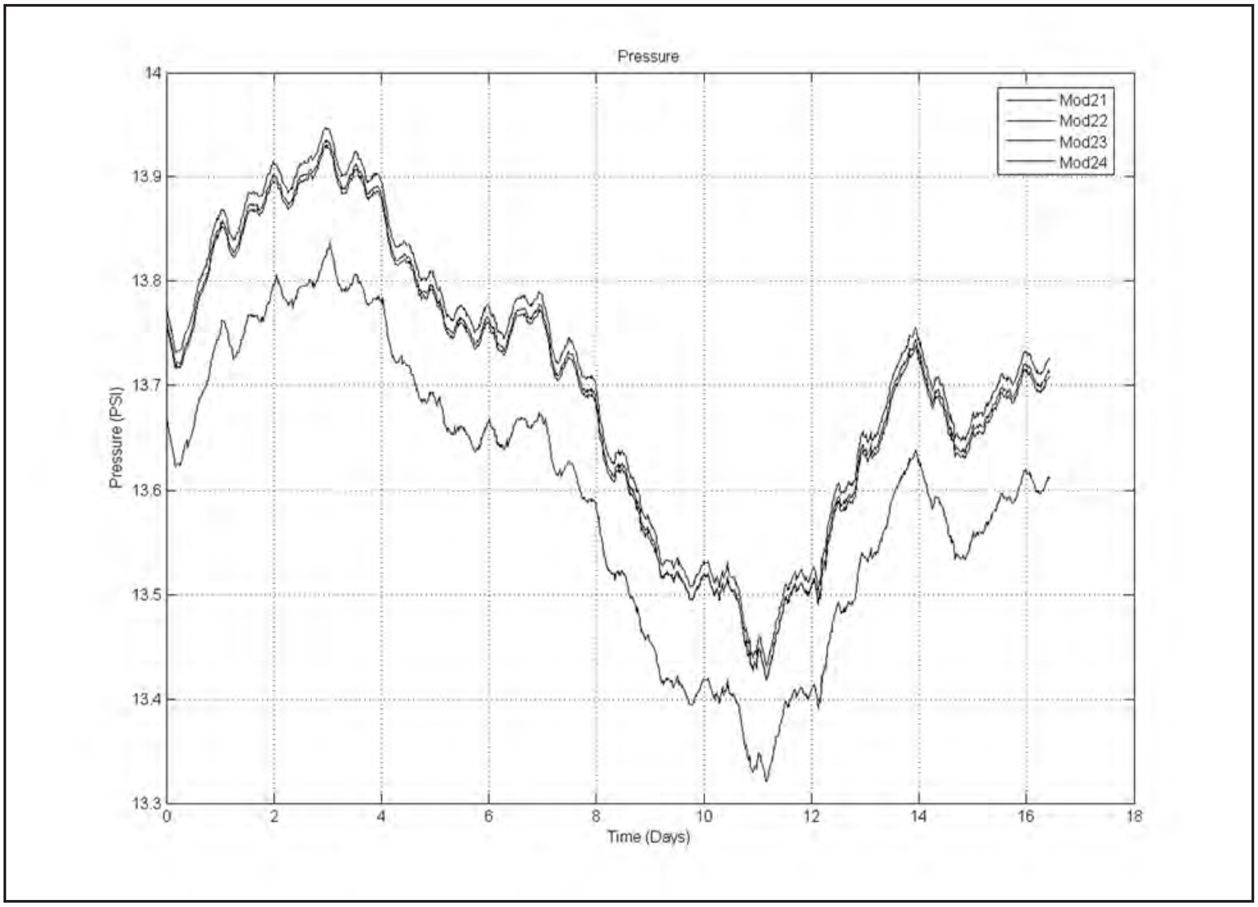

Figure 1 Sixteen days of air presure readings in Hellhole.

the electronics became the victim of severe charge build up, such as when lightning is directed to the caves during the mildest of storms or due to other charged-particle releases. The analysis performed on this problem has been directing unprecedented advancement in karst and underground facilities research.

In order to develop a system that can withstand and dissipate this charge due to lightning and natural/self-potential phenomena, we first had to measure this property. The charge build up was found to be very rapid, a 0.25 second pulse width was observed with a magnitude that was off the scale. This charge build up was found on the conduit and was being dissipated into the sensitive electronics, creating multiple failures. There was no direct correlation between lightning in the immediate region and this charge build up, further research would have to be done to determine the correlation between these events and lightning events further from the site. One relevant detail that is currently under investigation is that destruction of telephone equipment in specific regions has been known in this region of Germany Valley. The local phone company was noted at saying "it seems like the same people are always having trouble with their phones — these are legitimate problems, its always the same people though." This, along with additional literature, suggests that caves can be challenging environments in which to operate electrical equipment [1, 2].

Once the source of the problem was identified, a grounding system had to be developed and put in place before the cave closings of Hellhole and Schoolhouse Cave. Due to the rapid onset of charge, a total of three grounding rods had to be placed at Hellhole, one on the surface, one in the entrance room and one further back in the cave.

An example of the data can be seen in Figure 1 which shows 16 days of air pressure taken from several different locations inside of Hellhole and in one position outside the entrance.

Due to the sensitivity of the instrumentation and significant mathematical processing performed by Extreme Endeavors, the various frequency components were analyzed for correlation between the in-cave and out-of-cave sensors as shown in Figure 2. The analysis has revealed significant pressure and temperature oscillations on the daily and twice-daily cycles, with the twice-daily variations generally being slightly dominant. Through further analysis of this pressure variation, even the slightest change in the cave's environment can be detected.

Thermal anomalies were also detected that are currently under investigation, most of the temperature data from the caves is directly correlated to the surface temperature as shown in Figure 3 and Figure 4. With a relative accuracy of 0.05° Fahrenheit, the in-cave modules were sensitive enough to pick up even the most minor fluctuations in the underground passageways. A similar frequency analysis has been applied to the temperature data, revealing a truly fascinating result: many of the passageway temperatures are directly correlated with the outside temperature; however in certain passageways there was a direct anti-correlation between the in-cave and out-of-cave temperature.

The intricacies and complexity of this monitoring challenge, coupled with the engineering and access requirements, where Extreme Endeavor's engineers must rappel 180 feet into a pit make this project one of tremendous interest to other organizations. These caves are well known by karst researchers around the world, even the U.S. Military and intelligence agencies are expressing interest in this technological advancement.

Throughout this project, Greer Industries realized one thing which led them to work with Extreme Endeavors and Consulting. Conditions within caves are unique, requiring specialized considerations for sensors and monitoring. Therefore, special designs of components have been incorporated into the total system design as a means of addressing the ultimate application: remote data collection from within the caves. For instance, static electricity builds and discharges repeatedly within a cave environment. Lighting strikes outside of a

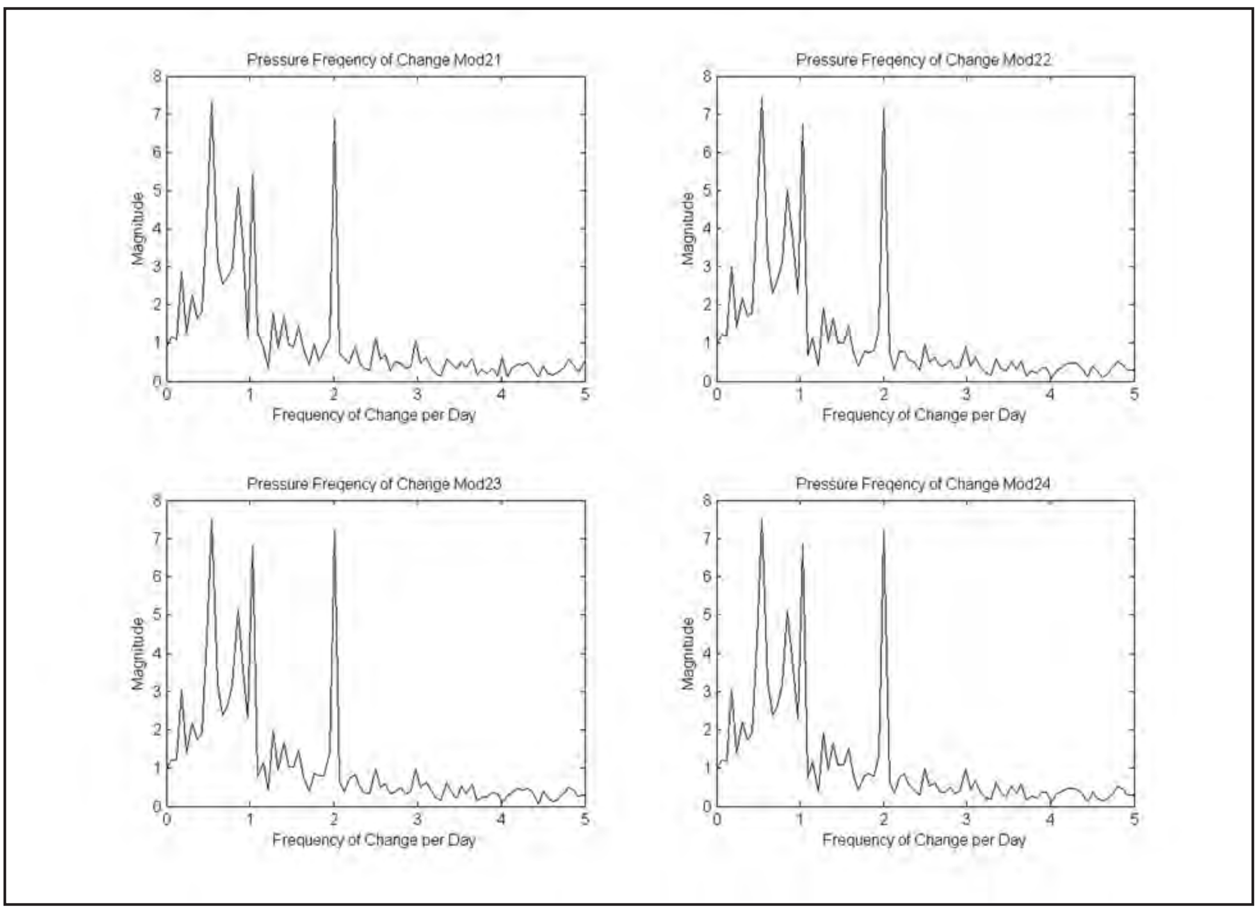

Figure 2. Pressure frequency of change inside and outside of the cave.

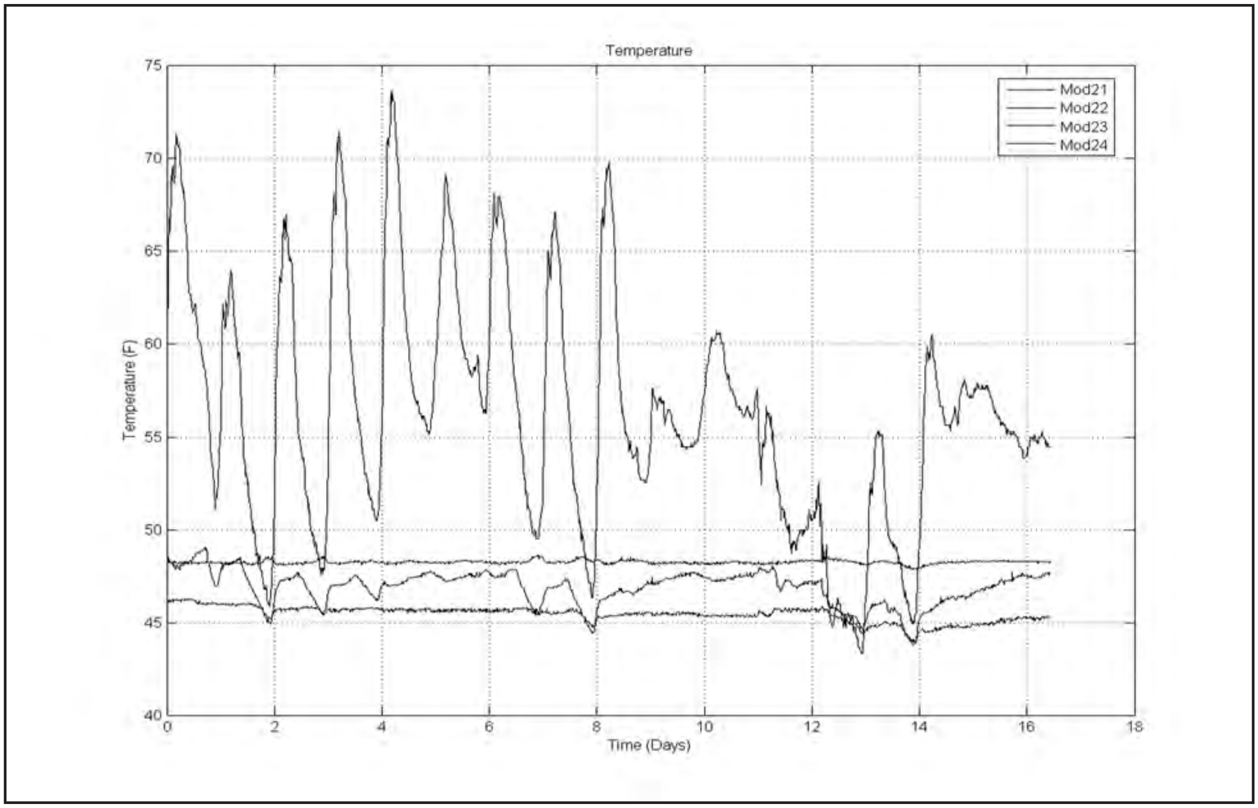

Figure 3. Sixteen days of air temperature reaings .

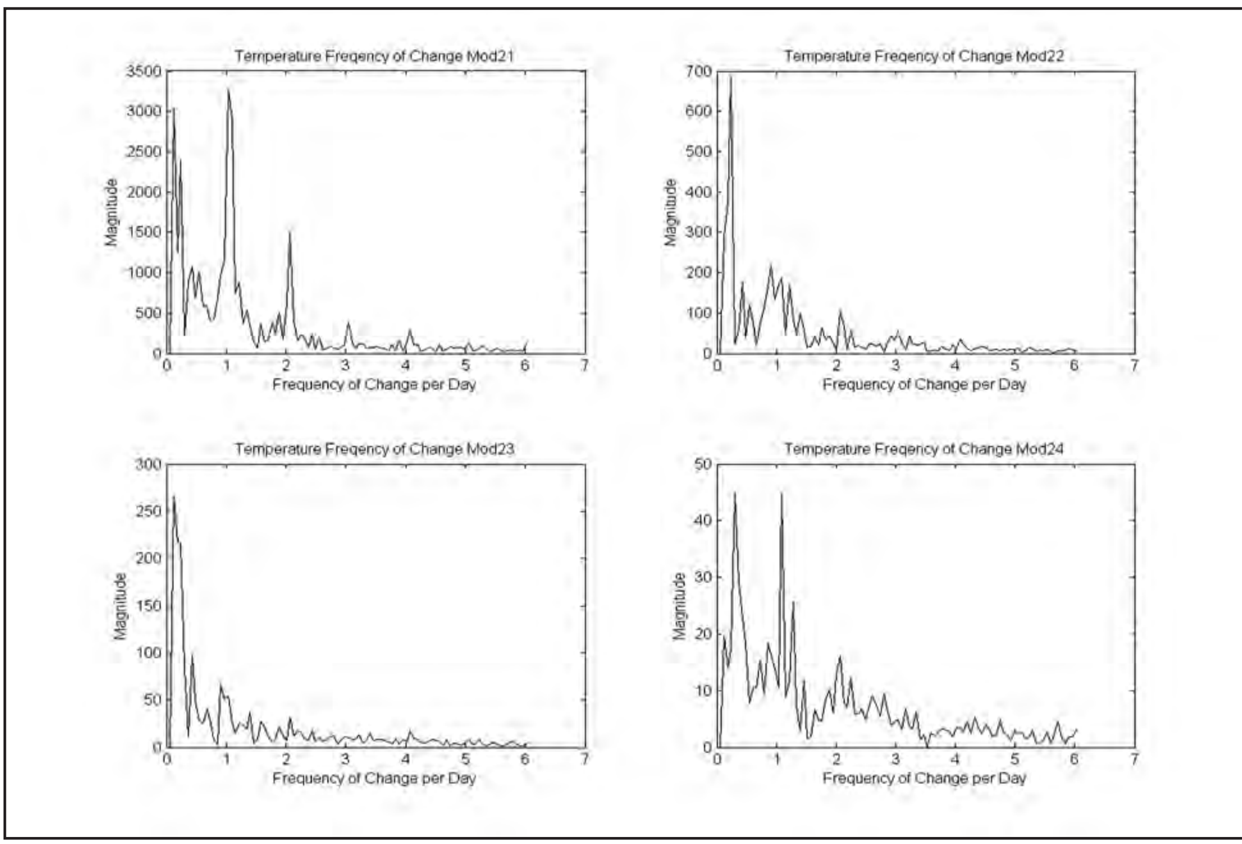

Figure 4. Temperature frequency of change inside and outside of the cave.

cave frequently dissipate within the cave, causing damaging voltage spikes to electronics. Extreme Endeavors and Consulting sensors are isolated from their containers via non-conducting posts and the transmission lines between the sensors are grounded in multiple places — all in an effort to mitigate static charge build up and enhance dissipation throughout the system. This has helped some, yet research is currently under way to locate other charge induced spikes, which in turn is defining the earth potential around caves, providing us with even more information about the surroundings and the reason the endangered species of bats select these particular caves for hibernacula locations.

Conclusion

What may initially seem like a simple engineering task of just monitoring temperature and barometric pressure within a cave has several other areas of concern that must be addressed in order to provide a satisfactory overall solution to the engineering task. Awareness of these extenuating circumstances is one component of Extreme Endeavor's background and experience within hazardous and/or harsh environments.

The overall ecological advantage provided by this project has been gained through engineers at Extreme Endeavors working together with biologists from the West Virginia Department of Natural Resources, U.S. Fish and Wildlife Service biologists, Greer Industries, the mining industry, and the West Virginia Department of Environmental Protection. These are just some of the physical reality issues in dealing with cave monitoring (similar types of physical issues come into play with other Extreme Endeavors and Consulting monitoring systems). After these engineering problems are reviewed for these physical system constraints, Extreme Endeavors and Consulting staff and engineers also consider the human factor of the systems. With careful and planned engineering solutions, both physical and human system risks can be mitigated.

Lastly, any engineered technology, whether in some remote, Antarctic outpost or on your living room coffee table, is only as good as the technical support for that product. Extreme Endeavors and Consulting has not only created a means of monitoring within a harsh environment, but also provides continued support of these monitoring systems by working in conjunction with all parties involved, while continuing to improve the technology. Products operating in harsh environments require much more hands-on engineering monitoring and support. It is widely understood that electronics, operating within the optimum environments — air-conditioned rooms, surge protected power, and so on, have long and useful lives. At the same time, once electronics are subjected to extreme conditions, support of that product within that environment is very critical.

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THE FORGOTTEN BAT CAVES: RECOGNIZING AND MANAGING BAT CAVES EVEN WHEN THERE ARE NO BATS

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Abstract

The popular wisdom is that the most important bat caves have been identified and protected. However, those caves are only the ones where researchers have recently found bats. We are now learning that bats may have been displaced to those sites due to disturbance in their historically-preferred caves. Instead of thriving in a cave with optimal conditions, many colonies are now barely hanging on or declining in less-suitable sites. The preferred caves are usually abandoned due to uncontrolled visitation ("there are no bats using the cave, so there is no reason to stay out"), or have been modified through commercialization efforts, including saltpeter mining. If we identify these overlooked sites and determine why they are no longer being used we can hopefully restore them as prime hibernacula. This allows more available habitat for bats, especially the endangered Indiana bat, where over 50% of the known population hibernates in only eight sites.

BAT GATES FOR LARGE COLONIES AND MATERNITY SITES

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Abstract

Bat gates have steadily evolved to provide increased security while becoming more ecologically transparent. Recently-developed modifications to the standard horizontal bat gate include cupola gates, flyover (or half) gates, bay-window gates, window gates, chute gates, and combinations, such as a bay window with a chute. Gate location is critical, and the numbers of bats and timing of cave use are critical to the design. Engineering becomes more complicated with modifications, and novices should consult with experts before attempting to construct any bat gate. But almost any bat colony in any type of cave or mine can now be protected by a secure gate without negative impact to the cave ecosystem.

THE MDC METHOD: COUNTING BATS WITH INFRARED VIDEO

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Abstract

A relatively inexpensive method is presented for recording bat emergences with Digital8® or mini-DV camcorders and near-infrared lamps. The recordings may be visually counted or automatically counted with a computer program. The Missouri Department of Conservation developed a statistical sampling method, in which 40 percent of the video sequence is counted by one or two observers. This "MDC method" is discussed, in which a total estimate of the emergence is made with 95 percent confidence limits. A bat stopwatch counting method also is given. Some preliminary information is reported on a more expensive thermography method for counting bats.

Review of Bat Emergence Counting Methods

It is quite a challenge to accurately count bats as they emerge from a cave or a mine. It soon becomes too dark to count bats with the naked eye without illumination or night vision technology. The speed and size of bats can also present problems. These aspects combine to make resolution of individual bats during an emergence difficult. Finally the fluctuation in the number of bats exiting at any given moment frustrates attempts at simple rate estimates.

Besides methods for counting bats in their roost, a few emergence count methods have been used:

- Wild guessing (must have been a million of them!)
- Flight duration (weather, season, and hunger-dependent)
- Counting on fingers and toes (tend to run out of them)
- Educated guessing (or uneducated)
- Counting on clickers (wear out your thumb)
- Skip-minute counting with night-vision or headlamp (good)
- Stopwatch method with several observers (better)
- Near-infrared (incident light) videography (better)
- Far-infrared thermography (excellent)

Considering the good methods, Elliott developed his stopwatch method, which involves several observers (Appendix A). However, large flights can overwhelm the observers' counting ability, and like most counting methods this may result in inaccurate estimates. He believes that visual estimates are usually conservative if done carefully. However, a consistent method may be all that is needed to monitor bat populations for changes. Although trained individuals can be proficient in conducting visual emergence counts (Sabol and Hudson 1995), years of experience may be necessary.

Materials and Methods

This study used relatively inexpensive Digital8® or mini-DV camcorders, near-infrared lamps, and slow-motion playback. The rationale is that humans and bats cannot see in the infrared spectrum (Table 1), so using commercially available near-infrared lamps will not disturb the bats, and we can record their emergences without altering their behavior. A small amount of red light is emitted by the near-infrared lamps, but this does not seem to alter the bat flight. Using a cluster-sample counting technique, it is possible to conduct emergence count surveys at a reasonable cost and calculate a statistical confidence interval for the estimate.

Spectral Region	Wavelength in nm
Human and bat vision	400-700
Near-infrared (near-infrared)	700-1400 Nightshot® 400–1400, peak 800
Mid-infrared	3,000-5,000
Far-infrared (FIR, thermal)	7,000–14,000 or more Indigo camera 8,000–9,000

Table 1. Human and bat vision compared to the infrared spectrum.

I began using a Sony® Digital8 video camera (Model DCR-TCRV310) in 2000 to record emergences of gray bats, *Myotis grisescens*, from Missouri caves. I used a Sony wide-angle lens to record the full width of an entrance (usually). Initially I used a Kodak® near-infrared gel filter on a powerful, 12-volt DC spotlight. The light was uneven, so I used pieces of a plastic milk jug or drafting mylar as a diffuser. The heat eventually melted the filter. I tried other light sources with an industrial, high-temperature, near-infrared filter, which was better. However, most of the light energy was filtered out, and there was insufficient illumination at large cave entrances.

In 2004 Steve Samoray, Sara Gardner, and I used Sony's small, near-infrared infrared lamps with AA batteries, but two or three of them were insufficient at large entrances. In 2005 we purchased two lamps from David Dalton at Wildlife Engineering, available in 20° or 40° beams. Steve Samoray, Jim Kaufmann, and I used the latter for close-in work at larger entrances with good results. The cost was about $600 for two lamps and a rechargeable 12-volt DC battery. Although many cameras can record in low light, the results are grainy, so it is important to have good illumination for clarity and contrast.

We generally set up at least 30 minutes before sunset at 5 to 10 meters outside the cave entrance with the camera on a tripod (Figure 1). Usually the camera was inclined upwards 20 to 30° to view the bats as they exited over the top of a half gate or through a chute gate (Figure 2). The ideal set up is to be inside the cave aiming at a relatively flat ceiling or wall with the camera oriented as perpendicular to the flight path as possible. It is important to avoid sky or vegetation in the field of view as the emergences begin in bright twilight, which overwhelms the near-infrared illumination.

In 2004 one Sony near-infrared lamp was mounted to the camera tripod and illuminated the center portion of the entrance, while the other two were placed on independent tripods. These independent tripods were placed 2 meters on either side of the camera and the near-infrared emitters aimed at opposite sides of the entrance to eliminate shadows. In 2005 the Wildlife Engineering lamps were mounted on tripods on either side of the camera to eliminate shadows as much as possible. A custom bar can be built to hold the camera and two lamps on one tripod.

Gray bats were usually observed milling about the entrance for a few minutes before a flight began. Recordings started shortly after sunset or after observation of several exits without re-entry were counted. The recordings continued until a limited number of bats were exiting (for example, five bats per minute) or the number of exits and entrances were equal. At many caves, after emergences, internal surveys were conducted to check if all bats had exited.

Although a continuous count of the entire

Figure 1. Video set up with Sony Digital8 video camera and Wildlife Engineering NIR lamps.

Figure 2. Gray bats emerging from the chute gate at Tumbling Creek Cave. Up to 41,000 bats were observed in 2005.

taped out-flight would yield the most precise estimate of the colony, this can be very time and labor intensive. Mike Wallendorf, biometrician, helped us develop a statistical sampling method in which 40% of the playback sequence was counted by one or two observers.

A cluster sampling method was used to reduce the number of minutes counted, but still maintain a high level of accuracy. The method uses collections or clusters as individual sampling units and is frequently used in situations when aspects of a population, such as total number, are difficult to obtain. In addition, the method was chosen because the rate of bats exiting varies greatly throughout the emergence. A graph of the emergence, using either the Stopwatch or the MDC Method, often appears as a jagged, normal distribution with an obvious peak of intensity during the middle and lower numbers on either side (Figure 3). Simple random sampling may indicate this pattern, but may also be affected by it. Cluster sampling allows for the intensity fluctuations and equally samples through the entire length of the emergence.

We divided the video into 10-minute periods. We then randomly selected four one-minute segments from each 10-minute period. We connected the camera to a large television with an S-video cable and divided the screen in half with a vertical tape. This allowed two observers to concentrate on much smaller areas and reduced the number of bats counted per observer. In many cases we also placed a horizontal tape for a visual starting line, so that bats that were crossing from one side to the other could be seen in advance. We then played back the tape at full speed or in slow motion (depending on

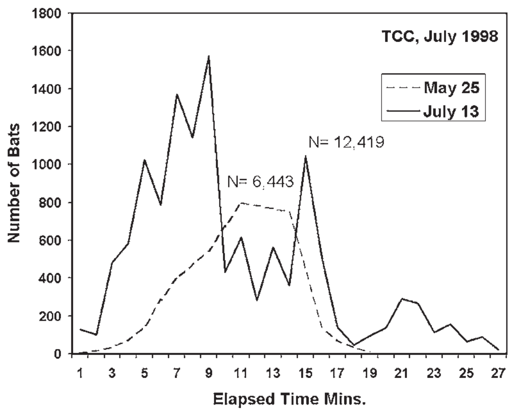

Figure 3. Comparison of gray bat emergences counted with the Stopwatch Method, Tumbling Creek Cave, 1998. The May 25 emergence (dashed line) represents pregnant females probably exiting from a single roost. The July 13 emergence represents mothers and young probably emerging from multiple roosts, and is less "monolithic."

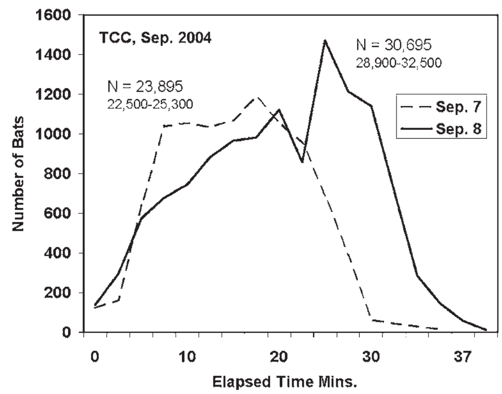

Figure 4. Comparison of two consecutive Gray bat emergences using the MDC Method, Tumbling Creek Cave, September 7-8, 2004. During this transient period the emergences can differ significantly from night to night. The 95% confidence intervals are given after the total estimates, N.

the exit rate) and counted the same four segments per period using hand-held tally meters. This resulted in four cluster groups overall.

All data were recorded on a data sheet, then entered into a computer spreadsheet, where we calculated the mean of the cluster groups and the estimate of the total number of bats. Sample variance among the clusters was calculated, and a finite population correction was applied to obtain a total variance. This was then used to calculate the 95% confidence intervals for the total count.

Results and Comparison to Other Methods

Since 2000 we have recorded 48 flights at 22 Missouri caves. At Tumbling Creek Cave, where we did most of our work, in 2004–2005 the error rate of this method was about ±7% of the estimate, varying from 0.5–15% over 15 emergences. A later improvement to the method involved counting 20-second segments every two minutes, reducing our sampling effort from 40% to 17%, with even narrower 95% confidence intervals. The lack of random sampling was not a problem because of the inherent variance in the bat flight itself. In general, we believe this method to be acceptable for monitoring population trends in gray bats and other bats, especially as the emergences vary significantly anyway from one night to the next in late summer (Figure 4). The variance increases after the young begin flying and the colonies are more mobile and enter a transient period for the autumn. We have

Cave	County	Date	MDC Method	Sabol Method
Smittle	Wright	July 13	16,418 ± 1,970	16,400
Mary Lawson	Laclede	July 14	71,615 ± 2,408	49,010
Beck Cave	Hickory	July 15	1 entrance = 736 ± 15	2 entrances = 1,705
Tumbling Creek	Taney	July 16	poor recording	31,985

Table 2. Comparison of the MDC and Sabol methods at gray bat emergences in Missouri, 2005.

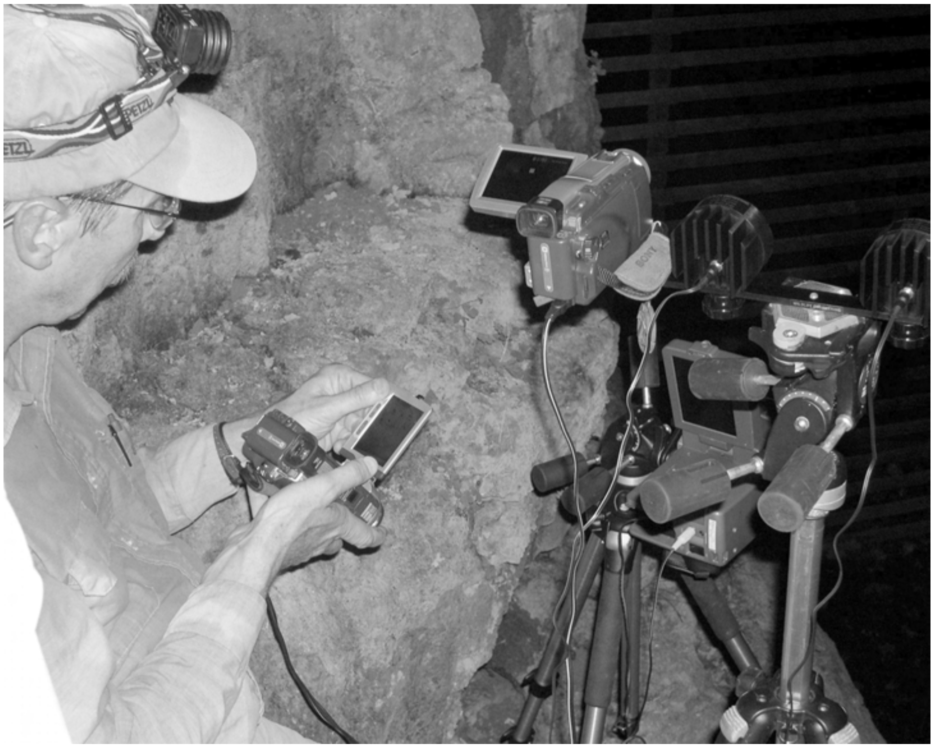

Figure 5. Bruce Sabol holds a mini-DV camera to record the output from the Indigo® thermal (FIR) camera, turned sideways at center right. Near-infrared lamps are mounted on a tripod at far right. The larger mini-DV camera on the left tripod is recording in near-infrared using Sony Nightshot®.

noticed at other caves that the error rate of the method itself can be high if the total is less than about 2,000, in which case it is better to count the entire tape. A different cluster sampling method might lessen the error in some estimates.

We also are comparing our method to the traditional guano measurements used in the cave at the end of summer. The Missouri Department of Conservation has many years of accumulated guano-based estimates, collected by Rick Clawson and many others. More field work is needed; however, at Mary Lawson Cave on June 21, 2004, we obtained a video estimate of 39,450 ± 3,400. On the same night after the bats emerged we obtained a guano area estimate of 54,400, 27% higher than the video estimate.

Previous studies successfully used thermal imaging to record emergences (Frank *et al*, 2003; Sabol and Hudson, 1995; Melton *et al.* 2005). We worked with Bruce Sabol, U.S. Army Corps of Engineers, in 2005 to compare our methods (figure 5), simultaneously recording bat emergences at four Missouri caves (Table 2). Sabol's method (pers. comm.) uses high-contrast video taken with an Indigo® thermal (FIR) camera, recorded on a mini-DV tape. Sabol's thermal camera usually is set to the side of the entrance for a view nearly perpendicular to the emergence. With no wide-angle lens for the special optics, the camera is turned sideways to obtain a cross-section of the flight. The results are transferred to a computer for video processing in two steps. The first step compares one video frame to the next to obtain moving bat vectors. In another program the researcher then draws a polygon counting frame in or around the entrance, and the program counts the bat vectors leaving the frame for a total count. In Missouri, we obtained two good simultaneous recordings to compare our methods, summarized in Table 2.

The videos for Beck and Tumbling Creek could not be compared. The two estimates of the Smittle Cave emergence are within 0.1% of each other. However, the two estimates for Mary Lawson differ by 31.6% agreement, or 22,605 bats. We do not believe that the MDC estimate of 71,615 for Mary Lawson is wrong. We suspect that our current cluster sampling method, in this instance, could cause an underestimate, so we are trying a different method that samples more frequently and provides a higher estimate for a larger emergence. We are also looking for a method of estimating the instantaneous exit rate at many times throughout the flight, which could increase the accuracy and reduce the labor required for the estimate.

We can only speculate about the large difference in estimates at Mary Lawson Cave. Perhaps the difference in vantage point between Sabol's and our camera was important, especially with larger emergences where bats might obscure each other in a lateral view instead of an upward or frontal view. There could be other reasons why the two recordings resulted in different estimates.

The next step will be to refine these estimation methods and calibrate them against each other and other methods, if possible. Although many biologists would want to use the Indigo camera, available from FLIR Systems, it currently costs about $30,000. The mini-DV and near-infrared lamps we currently use cost about $1,500. Sabol is investigating other thermal cameras in the $8,000–15,000 range. Both of these methods are still being developed, but they are promising.

Acknowledgments

The Missouri Department of Conservation, Resource Science Division, funded this work. We thank Mike Wallendorf, biometrician for Missouri Department of Conservation, for developing the cluster sampling method we used in this study. David Dalton provided excellent advice and infrared lamps. We are grateful to Tom and Cathy Aley for use of their facilities at the Ozark Underground Laboratory and Tumbling Creek Cave. Thanks to the many people who have assisted us in the field and laboratory: Anna Ford, Bruce Sabol, Bob Currie, Rick Clawson, Mick Harvey, Barbara Singleton, Kenzie Kaufmann, Sage Kaufmann, Christine Doerr, Maria Doerr, Kevin Hedgpeth, Mike Hubbard, Brian Miller, Jocelyn Korsch, Mike Skinner, Jean Mayer, Steve Paes, Mike Slay, Rhonda Rimer, Cindy Schweitzer, Ken McCarty, Jane Lale, Gladys Rigsby, Cindy Hall, K. Albrecht and T. Korsch.

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Appendix A. Stopwatch Bat Counting Method

This is a modified "skip minute" method using headlamps and stopwatches. I originated this method in Texas for counting *Myotis velifer* (cave myotis) at Government Canyon Bat Cave, where I did two emergence counts in 1995. On one trip I entered the cave after the outflight to measure the fresh guano area, and estimates from the two methods were within 13% of each other. Since 1998 I have used this method for counting *Myotis grisescens* (gray bats) at Tumbling Creek Cave and McDowell Cave, Missouri.

I use two or three observers to count, each with his/her own electronic watch. The reason for this is that each can operate his own watch by touch in the dark. An alternate method would have the team leader time the count out loud by his own watch, but that would require looking at his watch for the exact time, and this causes a loss of data.

This method is satisfactory for small to medium bat emergences, but the observers can be overwhelmed by larger flights and may not be able to keep up. With no statistical analysis this method is only an approximation, but it seems to be self-consistent among observers and it is better than wild guessing or just timing the flight. Some flights can stretch out because of cool temperatures, rain or other factors. Considering various error sources, I believe that this stopwatch counting method usually results in a slight underestimate, because one cannot see all of the bats and one can fall behind in counting. If the observers are careful, it will not overestimate the number of bats.

Procedure:

1. Have two or three people count, each with a stopwatch or stopwatch function on their wristwatch, a headlamp, and something comfortable to sit on.

2. One person is the team leader who will call the

count intervals and record data. Later he will do the spreadsheet calculations. It is best to do that right away before your memory fades.

3. Arrive just before sunset and find comfortable spots above the entrance to sit. You might even want to take something to cut limbs and brush away for better viewing. This method works only at entrances where you can sit above the entrance so your headlamps won't shine in the bats' eyes. Don't bother with red filters — you would not be able to see well. Use moderately bright headlamps with wide beams, not flashlights.

4. Record date, personnel, location, official sunset time, temperature, moon and weather conditions. When the bats start to fly, usually about 15–30 minutes after sunset, record the start time. Usually they start with just a few scouts who come out and go back in for a few minutes. Try to scan your light side to side and get a count of the whole flight path if possible. This way each person is a different estimate of the whole thing, not part of the thing.

5. Record observations every two minutes. When enough are coming out steadily, call the first stopwatch count. You say something like "Let's count five bats. Ready. Go!" Each person silently counts five bats while starting and stopping his watch. Then each calls in his data, and you record them in columns like in the spreadsheet. You could start with 10 or 20.

6. As the flight increases, step up to 50 or 100 bats. Just gauge it so the count does not go over a minute. This gives you a little time to write data and quietly discuss things before the next two-minute count.
7. If you get behind, decrease the size of the count. At 50 or 100 bats you should count by 5s or 10s, not each one. Also, you are estimating the net number that fly out. In the first part of the flight they mill around and go back in, and you have to estimate the net number that came out (for example ten flew out but five went in, so the net is five out.) As the flight increases almost none go back in. At the end when the flight drops off, some mill around again and go back in.

8. Enter the data into a spreadsheet, which averages the count over the different observers for each time segment, obtains a rate of bats per two minutes, then totals the all the two-minute estimates. This is then graphed. I can provide an example Excel file upon request.

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ECOLOGICAL RESTORATION OF STUART BAT CAVE, KICKAPOO CAVERN STATE PARK, TEXAS

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Abstract

Stuart Bat Cave, formerly known as Green Cave, is a well-known but poorly studied Mexican free-tailed bat cave in west Texas. Populations were estimated at up to ?? million. It was mined for guano until 1957 with a shaft dug into the back of the cave for easier guano extraction, but the change in airflow and microclimate caused almost total abandonment by the bats. Texas Parks and Wildlife purchased the ranch in 1986 to create Kickapoo Cavern State Park. The author coordinated volunteers from the Texas Speleological Association in capping the artificial entrance in December 2002, and began monitoring temperatures and humidity in the cave at that time. The situation was improving until Texas Parks and Wildlife decided to create a bat viewing area without consulting Bat Conservation International or even their own biologists on the design. The worst part was a handicapped-accessible sidewalk across the mouth of cave. Soon after construction was completed, consultation forced Texas Parks and Wildlife to agree that the platform in front of the cave had to be removed. Once again Texas Speleological Association volunteers mobilized, devoting 585 man-hours to breaking up and removing the thick reinforced concrete, and regrading and seeding the entrance slope. While still not perfect, the restored entrance is more bat-friendly and serves as a lesson on how not to create a watchable wildlife area. Populations seem to be rebuilding, but further observation is needed.

LAVA CAVE MANAGEMENT IN HAWAI`I VOLCANOES NATIONAL PARK

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Abstract

Lava tubes and other caves are major features of Hawai`i Volcanoes National Park that include important geological, mineralogical, paleontological, archeological, biological, cultural, recreational, and other resources. Although caves were known and used by Hawaiians for hundreds of years, and by more recent Island residents and visitors since they began exploring Mauna Loa and Kilauea Volcanoes, systematic inventories began only within the last 30 years. National Park Service funding allowed the National Park to conduct a resource inventory of selected caves in 1990–1991 by a team including an archeologist, biologist, geographer, and National Park Cave Specialist. The first Hawai`i Volcanoes National Park Cave Management Plan was approved in 1990. Between 1994 and 1995 a monitoring program was implemented in a limited number of caves. In 1995 the National Park hired its first permanent cave specialist, and the program was managed by the Cultural Resource Manager. Additional cave inventories were conducted between 1998 and 2000 when the program protocols were revised. The cave inventory program remained active and monitoring was re-instituted in 2004. Currently Hawai`i Volcanoes National Park cave management staff continues with an active program of cave inventory, mapping, and monitoring. Current and future projects include inventory of Kahuku lands recently added to the park, continued archeological and biological surveys, and development of a monitoring program for all parks with caves within the Pacific Islands network region.

Contribution No. 2006-006 to the Hawai`i Biological Survey

Introduction

Hawai`i Volcanoes National Park is located on the island of Hawai`i, part of the most isolated island chain in the world (Figure 1). Hawai`i Volcanoes National Park is located on two active volcanoes, Kilauea and Mauna Loa, the latter being the largest single mountain on earth. The park stretches from sea level to over 13,000 feet elevation and contains 333,000 acres. It has been an International Biosphere Reserve since 1980 and a World Heritage Site since 1987. The park includes at least nine ecological zones; near shore marine, seacoast, lowland, mid-elevation woodland, rain forest, upland forest, subalpine, alpine, and aeolian. Both volcanoes have recent lava flows, on Mauna Loa the

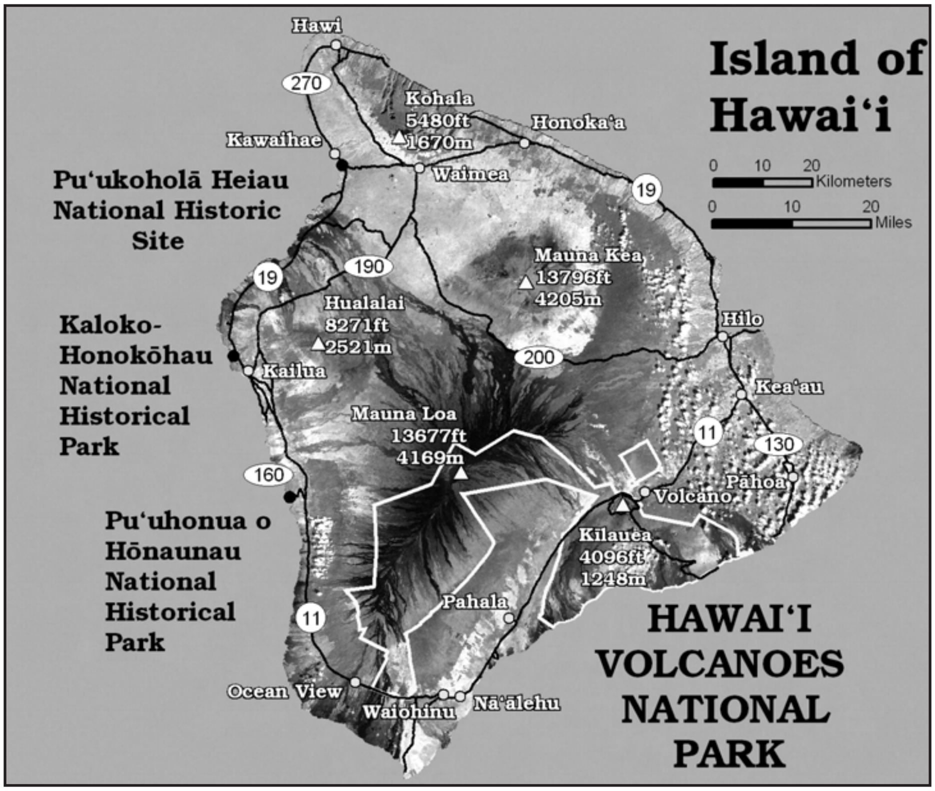

Figure 1. Map of Hawai`i showing Hawai`i Volcanoes National Park.

most recent being 1984, while on Kilauea a nearly continuous eruption has been active from 1983 to the present. Numerous lava caves occur throughout the park. These include lava tubes, crater vent caves, fissure and rift zone caves, pressure ridge caves, tree mold caves, and sea caves among others. Many lava tubes are quite large and some are several miles long. They include important geological, mineralogical, paleontological, archaeological, biological, cultural, recreational, and other resources. Hawaiians regularly entered and used lava tubes before European contact with the Hawaiian Islands (Figure 2).

Figure 2. Hawaiian petroglyphs in Hawai`i Volcanoes National Park lava tube. Photo by Fred Stone, courtesy of Hawai`i Volcanoes National Park.

Lava tube formation

Lava tubes form rapidly and begin eroding almost as they form. Two types of basaltic lava occur: rough, clinkery a`a and smooth, ropy pahoehoe. Lava caves usually form in pahoehoe flows, though a`a flows are sometimes tube fed. Pahoehoe is much less viscous than a`a, and the crust generally does not stick to the molten flowing lava. Fluid pahoehoe often spreads out in thin, sheet-like flows near the flow margin. The flow advances by extruding lava toes that crust over and break to create new toes. Overflows of lava build layer on layer and fuse to older surfaces poorly, leaving numerous gaps preserved between each flow unit.

Older toes feeding the advancing edge grow and become distributary tubes. These surface distributary tubes are usually small and rarely connect to longer lava tubes. However, fluid pressure can sometimes inflate them to small cave-size lava tubes. Also, they are often numerous within flows and provide a significant habitat for cave animals. Remnant sections occur as upper level mazes in lava tubes and as small shallow mazes on the surface.

Figure 3. Native hapu`u tree ferns in lava tube entrance. Photo by Fred Stone, courtesy of Hawai`i Volcanoes National Park.

Upslope from the advancing front, the edges solidify first, so that the flow soon becomes channeled between the vent and the flow front. Overflows cover older layers, thickening the flow and deepening the channel. Thus, lava streams advance downslope and deepen within levees built by overflows and spatter. Long lava tubes form by the crusting over of these pahoehoe rivers. Three distinct mechanisms can create a permanent roof: (1) a solid crust can grow across the stream from each edge or downstream from an already formed roof; (2) spatter and overflows can form arched roofs over streams; and (3) floating plates of crust can jam across the stream and anchor a new roof (Peterson *et al*., 1994). Once established, these roofs thicken by accretion of lava on the lower surface and by overriding flows on the upper surface. Surges or reductions in flow volume can destroy a developing roof; thus, roofs generally survive only in steady, low to moderate volume flows that last long enough for the roof to form and stabilize, usually at least several weeks. Limited observations suggest that the longer the flow the more stable the resulting cave. Molten lakes that store lava and drain into the tube are very important in moderating the flow, allowing the roof to stabilize. Skylights along the tube act as pressure valves, which allow overflows to thicken the roof downstream without destroying the established tube (Figure 3).

There is good evidence that well established active lava streams can erode the substrate. In some caves in Hawai`i Volcanoes National Park and a few other caves on Hawai`i Island, there are fossil plant remains and charred soil layers embedded in the cave wall, indicating that the flowing lava cut its way down through the pre-existing ground surface as it flowed (Howarth, Stone, and Pearthree, unpublished data).

Active lava tubes are remarkably efficient insulators; at Mauna Ulu, they carried lava over 12 kilometers from the vent to the ocean with only a 10°C loss of temperature (Peterson and Swanson 1974). Thus, pahoehoe lava flows build and repair their own conduits or lava tubes, which then transport the lava great distances from the vent. This mechanism is now recognized as the major factor in building shield volcanoes (Peterson and Swanson, 1974; Peterson *et al*., 1994). It also means that pahoehoe flows can cover large areas and create abundant underground habitats for cave animals.

Precontact use by Hawaiians

Lava caves were an important resource for Hawaiians who lived in the area that now forms the park. Many caves were used as living sites, particularly those along the coastal zone where fishing and agriculture were practiced. In other zones, caves were used for temporary shelter by forest gatherers, bird catchers, or travelers. These contain leveled sleeping areas just inside the entrances. Lava tubes were the major source of water for much of the area in the park. Even in areas with high rainfall, the water rapidly infiltrates into the porous lava. In arid zones the lava tubes were one of the few reliable sources of water for human consumption and for agriculture. The water catchments in the lava tubes are still intact in many cases, with prop stones for calabash gourds (and even gourd fragments in some places) and ash and charcoal from the torches used to light the interior. Some tubes have pecked water holes and opihi (*Cellana* sp.) shell dippers still in place and thick ash deposits surrounding them (Figure 4). William Ellis, an early missionary to Hawai`i, in 1823 was traveling in the vicinity of "Kearakomo" (on the trail from Kilauea crater to the coast) and was ". . . so favored as to procure a calabash-full of water from the caves in the mountains, where it had filtered through the strata of lava, and was received into vessels placed there for that purpose." (Ellis, 1842). Small caves and openings in lava were used by petrels as nesting sites, and the petrel chicks were a major food source. Where the pahoehoe was suitable, Hawaiians sometimes broke open the shallow surface layer to create additional nesting sites for the petrels (Moniz Nakamura *et al*., 1998; Moniz Nakamura, 1999; Hu *et al*., 2001).

Lava tubes were used as hiding places and refuges in time of warfare. These tubes often have fortified entrances and living spaces on either side of a central walkway. A term in Hawaiian *pe'epao* refers to these secret caves. Refuge caves are known to occur elsewhere in Oceania including Easter Island, Mangareva, Tonga, the Reef Islands, and Samoa (Kennedy and Brady, 1997). Several park lava tubes have petroglyphs pecked into the smooth surface lining near certain entrances. In some cases, these petroglyph caves may have served as boundary markers. Caves were also used for religious ceremonies, and as burial places.

Threats to Hawai`i Volcanoes National Park Caves

Lava flows create new lava tubes, but also cover and destroy old lava tubes. This natural process is recognized in Hawaiian legends of Pele the creator and destroyer. Lava flows can also cause fire in dry areas of the park. Many of the native plants are resistant to natural fires, but with introduction of fire climax grasses, fires occur more often and may burn hotter than natural fires, causing a loss of the native *`ohi`a* forests and their root systems on which the cave species depend. Invasive species including pigs, sheep, goats, and the fire tree (*Myrica faya*) can destroy or out-compete surface vegetation (Figure 5). Archaeological remains in park caves are subject to looting by vandals. In one case, a section of petroglyph appears to have been broken loose from a wall lining and removed, only to be dropped, broken,

Figure 4. Hawaiian pecked water hole with `opihi (limpet) shell scoops and ash from torches (photo monitoring site). Photo by Fred Stone, courtesy of Hawai`i Volcanoes National Park.

Figure 5. Roots of invasive Myrica faya (white) and native `ohi`a (brown). Photo by Fred Stone, courtesy of Hawai`i Volcanoes National Park.

and abandoned in the cave entrance (Stone, 2005 unpub). Accidental destruction of roots, cultural deposits, and formations by carelessness or ignorance by those entering the caves often occurs. This is particularly dangerous when tourists without knowledge of unique features enter caves without permission from the park. A section of fragile sand castle deposits was found to be trampled after entry by a group of 30 people from Germany who signed the register in the cave, and wrote that they learned of the cave from a German publication. Ash piles and gourd fragments near water catchment areas can be trampled, as can bone deposits from extinct birds. Graffiti and garbage are left in caves that are open to the public or in areas easily accessible to the public. Trash that is clearly of modern origin should be removed; however, some trash can be historic in nature and should be documented as part of the historical use of the cave. Graffiti has been found in cave slime deposits, and the dark portion of Thurston Lava Tube needs regular cleaning due to its high visitation.

A problem that has occurred in other areas, but has not been documented in Hawai`i Volcanoes National Park, is the change in air flow that occurs when entrances and passages are opened by explorers or managers to allow for human access. This changes the pattern of air flow through the cave, causing areas with high humidity to dry out, and reducing the area of deep cave available for cave adapted species.

Park Cave Exploration, Inventory and Management

Thurston Lava Tube was found by Charles H. Birdseye of the U.S. Geological Survey in 1912. Birdseye discovered the middle skylight while surveying the boundaries for the proposed national park. In 1913, L.A. Thurston and a large group explored the cave (Apple, 1986). It soon became a regular stop on the tourist route.

The first systematic cave inventories occurred in 1959 and 1965 by teams of archeologists from the Bishop Museum (Emory *et al*., 1959; Emory *et al*,. 1965; Smart, 1965). Such National Park Service driven archeological surveys have led to the inventory of over 50 cultural cave sites in the park with many more still undocumented.

Speleological inventories with a particular focus on mapping and cave morphology began in the 1970s with the work of Bill Halliday and Stefan Kempe. Chris Wood led a British expedition that mapped Ainahou Cave in the early 1980s (Wood, 1981), and Swiss caver George Favre mapped the Ka`u Desert Pit Craters and Mauna Ulu Crater Cave.

Hawai`i Volcanoes National Park cave biological studies began in 1971 with the discovery of cave adapted species by Frank Howarth in Bird Park Cave. He has continued his studies of Hawai`i Volcanoes National Park cave biology up to the present, and has led an international team of scientists in the study of the systematics, behavior, physiology, communication systems, and DNA of park invertebrates.

In 1976 Storrs Olson and Helen James with

Alexander Wetmore began long-term studies on the paleontology of extinct birds in Hawaiian caves and sand dunes. Bird bones of unkown taxa were more recently found in National Park caves and bat bones were recorded in 1992. (Howarth *et al*., 1994; Stone, 2005 unpub). Collection and further identification of the materials by such specialists is needed.

Following these early inventories the park began to systematically plan the management of the caves in the early 1980s. R. Seibert wrote the first Draft Lava Tube Management Plan for Hawai`i Volcanoes National Park in 1982. Management of caves within National Park Service lands was later strengthened with the Federal Cave Resources Protection Act of 1988 that required federal land managers to develop plans to protect cave resources.

In 1990 Susan Heftel-Liquido and A. Kikuta wrote a second draft management plan for Hawai`i Volcanoes National Park Caves, and in the same year the Park completed a Draft Environmental Assessment for the plan. Soon after the first cave management plan was adopted for Hawai`i Volcanoes National Park in 1991 the park followed with the development of a detailed proposal for Hawai`i Volcanoes National Park cave inventory. The subsequent inventory project that followed the 1991 proposal lasted through 1993. The final report (Howarth *et al*., 1994) submitted in 1994 addressed four principal objectives:

(1) Refine protocols and a standard inventory form for assessing cave resources and recording information on caves.

(2) Inventory and assess selected accessible park caves, their resources, threats, and management needs.

(3) Develop a computer database that can be later converted to a GIS system and begin to input data from inventories.

(4) Document methods for monitoring cave resources within the park.

The assessments completed as part of this project resulted in values that were assigned to caves based on presence of resources (see sample below). As a result of the inventory, an additional cave, Pua'po'o or Cockscomb Cave, was opened to the public for guided tours. Kipuka Puaulu Cave #1 was made available for recreational caving but only with an approved permit. The dark end of Thurston Lava Tube was also opened for self-guided exploration without the need for a permit. In 1994 Hawai`i Volcanoes National Park updated its Cave Management Plan and included many of the recommendations that were a result of the inventory program.

A main recommendation of the Howarth *et al*. (1994) inventory report was that regular cave monitoring, photo points, and registers be established. Staff from the Resources Management Division of Hawai`i Volcanoes National Park, began this program in 1993 and continued it through 1995. Photo points were established and entrance monitoring occurred in 22 caves and registers were placed

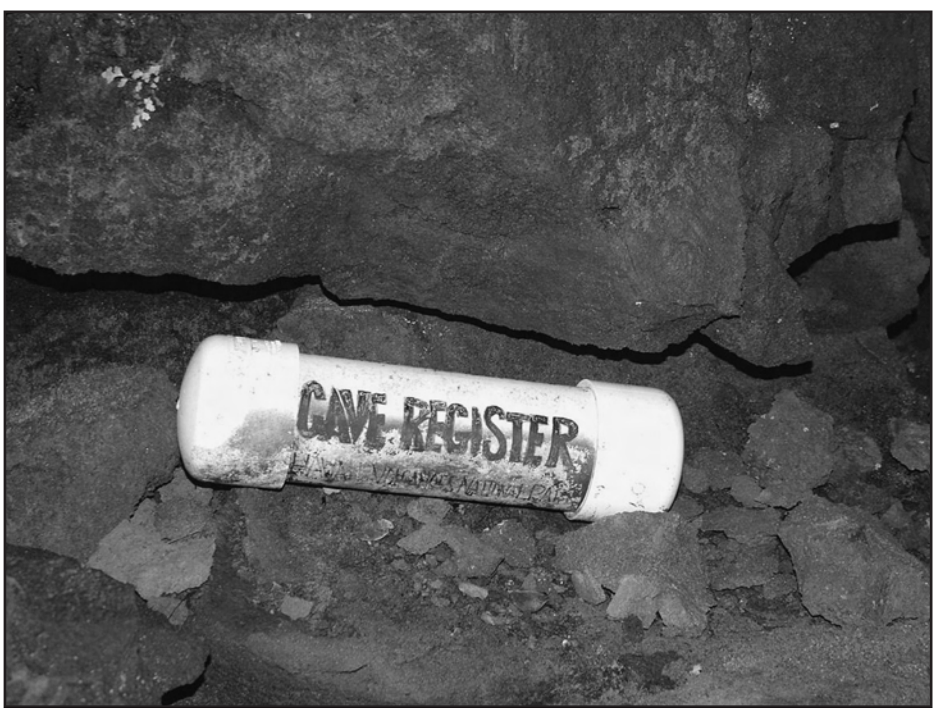

Figure 6. Cave register placed in park cave in 1993.
Photo by Fred Stone, courtesy of Hawai`i Volcanoes National Park.

in 20 caves. After 1995 the monitoring program waned although many of the registers remained in place. This program was revised in 2003 and currently 21 of the original caves are being monitored again (Figure 6). Caves selected for monitoring are near roads and trails where park visitors are most likely to encounter them.

In 1995 the park hired a Biological Technician whose primary task was to function as the first permanent Cave Specialist for Hawai`i Volcanoes National Park. One of his primary focuses was on traditional Hawaiian cultural use of caves. In addition, during this period the park began to work with the Hawai`i Speleological Survey on specific cave projects, such as the long-term surveys by Bill Halliday and Survey cavers of caves in Kilauea Caldera and initiated a survey for cave entrances on the slopes and summit of Mauna Loa and in the southwest corner of the park near *Kamo'oali'i*. A total of 22 cave systems were documented (Stock and Bumgardner, 1999). While strides were made in identifying new caves during this period, systematic cave monitoring lapsed. The Biological Technician held this position until 1999 when it was vacated.

In 2001 Hawai`i Volcanoes National Park utilized the vacancy to develop a professional series position and hired an Integrated Resources Manager. This individual was tasked to develop a program that would manage both the archeology program and cave resources. In developing this position, managers recognized the unique cultural aspects of the Hawai`i Volcanoes National Park cave program. In addition, the Federal Cave Resources Protection Act and the National Historic Preservation Act could provide both resources with the legal protections needed for preservation and management.

Since 2001 the cave inventories have expanded and intensive location and documentation of known caves has begun. A cave database has been developed and all known caves are being re-inventoried and condition assessments are being updated. By combining the cave and archeology programs, managers are able to better utilize the limited funding resources. Program funds from the archeological inventory program, for example, have been extended to the inventory of cultural caves. In addition, funding that has come from other sources specifically for cave management has been targeted for inventory and monitoring of all cave resources. A systematic program for relocating, inventorying and mapping all known park caves is well under way and is expected to be a multi-year phased project conducted primarily in-house and contracted specialists. In addition to the inventories, regular monitoring of selected caves has been re-instituted.

In 2005 as part of the overall inventory program, the Bishop Museum was contracted by the National Park Service to re-inventory the original caves surveyed between 1991 and 1993 to determine what changes have occurred (Figure 7). Several additional caves are included in the detailed inventories, totaling about 30 caves. This project has been a joint field effort by both the National Park

Figure 7. Frank Howarth conducting timed biological inventory in Bird Park Cave. Photo by Fred Stone, courtesy of Hawai`i Volcanoes National Park.

Service crew and the Museum. In addition to these in-house and contracted efforts, the National Speleological Society cavers have assisted in a survey of caves in the newly acquired Kahuku Park lands.

Future plans include development of Pacific Islands Network-wide inventory and monitoring program for all National Parks. Limited funding has been received and a contract between the Park Service and the Bishop Museum to begin the inventories in June 2006 has been agreed to. Hawai`i Volcanoes National Park is also strongly committed to continuing its integrated cave inventory and monitoring program.

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DEVELOPING A 3D MODEL IN GIS TO ASSESS THE POTENTIAL EXTENT OF THE JEWEL CAVE SYSTEM: A TOOL FOR MANAGING THE UNKNOWN

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Abstract

Park boundaries, and barometric airflow studies indicate that as much as 97% remains to be discovered. A first approximation of the maximum extent of humanly passable cave passages has been modeled in three dimensions, based on volume estimates from barometric air flow, constraints presented by geologic contacts, the water table, and known structural features. These relationships have been quantified and analyzed using structural and potentiometric contours from the U.S. Geological Survey Black Hills Hydrologic Study, surface and subsurface mapping by the National Park Service, and other sources. The model serves as an important management tool for an enormous resource that requires proactive measures to ensure its continued protection.

MAPPING SURFACE GEOLOGY TO PROTECT CAVE AND KARST RESOURCES OF THE JEWEL CAVE SYSTEM

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Abstract

Jewel Cave is a vast cave system in the Mississippian Madison Formation in the southern Black Hills of South Dakota. It is a resource that is still being discovered. Strong barometric winds in the cave have demonstrated that the 133 miles presently known represent only about 3% of the total volume. Thus, most of the cave system is yet to be found.

Maps of cave passages overlain by detailed surface geologic maps have demonstrated a spatial relationship between cave passages and geologic contacts, providing a general indication of where undiscovered passages are likely to exist.

They have also shown that hydrologic connections are directly related to the surface exposure of the two permeable subunits in the lower part of the overlying Minnelusa Formation. These exposures constitute zones of infiltration which, as a management tool, represent zones of vulnerability — areas where the cave is susceptible to impacts from surface activities via hydrologic connections.

The resulting maps have been used as a predictive tool to anticipate where the undiscovered portions of the cave might be found. This information has already been used to help prioritize efforts to protect the known and unknown portions of the cave system via a mineral withdrawal and a land exchange.

PROTECTING VIRGINIA'S CAVES AND KARST THROUGH THE ENVIRONMENTAL PROJECT REVIEW PROCESS

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Abstract

Within the Virginia Department of Conservation and Recreation, the Natural Heritage Program maintains a Project Review Office that screens a variety of proposed development projects for potential impacts to natural heritage resources. All projects involving state funds pass through this process, as do projects with potential wetland impacts, those subject to the National Environmental Policy Act, and those submitted voluntarily or as required by local governments. Emphasis is placed on protection of natural heritage resources — occurrences of rare plants, animals, or natural communities — and significant geologic formations. Caves designated as significant by the Virginia Speleological Survey and the Virginia

Cave Board, following the provisions of the Virginia Cave Protection Act of 1979, are treated as natural heritage resources during project review. For screening purposes, natural heritage resources are represented as conservation site — landscape areas where activities could impact one or more occurrences of natural heritage resources. Projects within two miles of a conservation site are reviewed for potential impacts to natural heritage resources. If these sites are cave-related, projects are sent to both the Karst Program and the Virginia Speleological Survey, because the Natural Heritage Program does not maintain a database of cave entrance locations. The Survey also provides information on additional caves and karst features not designated as significant, but potentially impacted by the project. This arrangement facilitates protection of caves without public ownership of cave locations. Seventy-two delineated conservation sites cover 151 of Virginia's nearly 400 significant caves. Caves awaiting conservation site delineation are represented by 3-kilometer radius buffers with centers offset from entrances.

Introduction

The mission of the Virginia Department of Conservation and Recreation Natural Heritage Program is the conservation of Virginia's biodiversity through inventory, protection, and stewardship. As a part of Natural Heritage, the objectives of the Virginia Karst Program are to conserve and protect the extensive biological and hydrological resources present in Virginia's karst regions. The Virginia Karst Program addresses these objectives through education, data development, and technical assistance.

An official survey of the National Speleological Society, the primary mission of the Virginia Speleological Survey is to gather and maintain an informational and survey database on Virginia's caves and associated karst features. The Survey's collections include three components: maps, other printed material, and a digital database. The Survey currently tracks over 4,300 caves, 369 of which were designated significant as of December 2005 under the provisions of the Virginia Cave Protection Act of 1979. The map database currently includes 1989 maps covering 1,483 caves.

Through its office of environmental project review, the Natural Heritage Program screens a wide variety of proposed development and conservation projects for potential effects on natural heritage resources. A natural heritage resource is defined as rare, threatened, or endangered plant and animal species, unique or exemplary natural communities, and significant geologic formations. Caves designated as significant under the Cave Protection Act are treated as natural heritage resources during project review. An additional 50 caves are home to natural heritage resources and are tracked by Natural Heritage, although they are not on the Significant Cave List. Only about 60% of the designated significant caves include other natural heritage resources.

For project review purposes, natural heritage resources are represented either as (1) conservation sites — landscape areas where activities could impact one or more occurrence of terrestrial natural heritage resources, or (2) stream conservation units — stream segments one mile downstream and two miles upstream of a documented occurrence of an aquatic natural heritage resource. Significant caves and occurrences of rare cave fauna or subterranean natural communities are currently represented by conservation sites or by surrogate conservation sites (discussed below). Conservation sites are assigned a biodiversity value (B-rank), depending on the rarity, number, and quality of occurrences of natural heritage resources within the site. Appendix A contains an explanation of the basis for B-rank determination. This method is the Natureserve™ standard, used by natural heritage programs throughout North America.

Projects submitted for review that are within 2 miles of a conservation site or are adjacent to stream conservation units, and have potential to impact natural heritage resources are referred to staff scientists or conservation partners with appropriate expertise, who determine whether further coordination by the developer is required to avoid or mitigate impacts. In the case of legally protected species or habitat, the Natural Heritage Program notifies and consults with the appropriate regulatory authorities. Projects within two miles of cave conservation sites, or which intersect surrogate conservation sites, are sent to both the Karst Program and the Virginia Speleological Survey. Additional projects in areas not within conservation sites, yet overlying karst topography, are also reviewed. The Survey plays a critical role in that the state does not maintain a comprehensive database

Entities Using Project Review	Type of Project
Federal Agencies	
Energy Regulatory Commission (FERC)	Interstate energy transmission projects.
Army Corps of Engineers	Projects affecting waters of the US and designated wetlands
Forest Service	Various projects (e.g., harvesting, prescribed burning, trail construction/modification)
National Park Service	Various projects (facility construction, trail construction/modification, historical restoration activities)
Fish and Wildlife Service	Various projects (e.g. species recovery plans, property acquisitions)
USDA Natural Resources Conservation Service	A variety of agricultural and urban best management practice implementations.
State Agencies	
Department of Transportation	All construction and maintenance projects
Department of Environmental Quality	Water Protection Permits - State waters including wetlands
	Environmental Impact Reviews for State Projects (all agencies) over $100K
	NEPA Reviews – Environmental Impact Statements and Environmental Assessments
Department of Game and Inland Fisheries	Various projects (e.g. stream restoration, Section 7 Funded projects)
Department of Agriculture and Consumer Services	Various projects (e.g. gypsy moth spraying, other pest control projects)
Department of Forestry	Various projects (e.g. Forest Legacy Program, conservation easements)
Marine Resource Commission	Joint Permit Applications-Impacts to state submerged bottomlands
State Corporation Commission (in coordination with DEQ)	Anything regulated by SCC, including power plants and transmission lines.
Regional Planning District Commissions	Projects with state or federal funding nexus
Local Governments	Projects with state or federal funding nexus
	Coordination for rezoning requests in compliance with Comprehensive Plans
Universities	Research and Teaching
The Nature Conservancy	Conservation planning and land/easement acquisition
Land Trusts	
Virginia Outdoors Foundation	Conservation easements
Local land trusts	Conservation easements
Consultants	Development projects; project scoping

Table 1. Sources of projects passing through state environmental review in Virginia.

of cave locations, leaving it up the Survey to identify caves of undetermined significance that may be impacted by a specific project.

Scope of Project Review

Table 1 summarizes the sources and types of projects passing through environmental project review. Many of these projects utilize project review to comply with environmental laws and regulations, including but not limited to the Clean Water Act, the National Environmental Policy Act, and the Endangered Species Act. The single biggest user of environmental project review is the Virginia Department of Transportation, responsible for about a third of the monthly workload. Proposed conservation projects such as implementation of best management practices and acquisition of easements or real property also commonly pass through project review, both to help avoid unintended impacts and to help better estimate their conservation value. Consulting companies frequently use project review to proactively identify environmentally sensitive areas to avoid when determining locations of development projects.

Unfortunately, many potentially high impact projects such as residential and commercial development do not pass through project review unless there is a state or federal nexus, such as a wetland permitting issue. Recently, however, some local governments have begun to require that rezoning requests pass through environmental review to ensure that they are consistent with the environmental protection component of local comprehensive plans.

Over 3,000 projects pass through the Natural Heritage Program environmental review office each year, and the number of annual projects is growing, with an all-time high of over 3,500 in 2005 (see Table 2). Of these projects, slightly fewer than 10% or about 300 per year are identified as having potential impacts to caves and/or karst, and are sent to the Karst Program and the Virginia Speleological Survey for further review. In Table 2, the higher number of karst hits prior to 2003 reflects that before implementation of the conservation site methodology, all projects in Virginia's 26 western karst counties were reviewed for impacts to karst.

Development of Conservation Sites for Caves

Prior to adopting the conservation site approach for natural heritage resource protection, projects were screened for proximity to element occurrences — documented locations of natural heritage resources. This resulted in review of many projects with little to no potential impact to those resources. The conservation site approach is superior in that it predetermines the area of potential impact, thereby reducing the number of projects selected for further screening. Development of conservation sites and stream conservation units for surface species is fairly straightforward, and can be accomplished in the office using a combination of aerial photographs and field notes. However, development of conservation sites for caves is not as straightforward, due to both the nature of the resource and the nature of the data.

The Nature of the Resource. Caves are three dimensional, subterranean features, and frequently extend beyond constrictions or blockages through which humans won't fit. In addition, the watershed

Calendar Year	Total Projects	Projects Reviewed for **Impacts to Caves and Karst**
2001	3388	626 (18%)
2002	3034	579 (19%)
2003	3112	176 (6%)
2004	3462	294 (8%)
2005	3514	298 (9%)

Table 2. Environmental Project Review and Karst in Virginia (2001–2005).

of streams or pool in caves with hydrological significance and/or rare aquatic fauna in many cases can only be determined by the performance of dye trace investigations. Thus in contrast to surface element occurrences, development of conservation sites for caves requires more in depth analysis of data and frequently new field investigations.

The Nature of the Data. As noted above, the Commonwealth of Virginia does not maintain a comprehensive database of cave locations or maps. Publication of cave locations in Douglas (1964) and Holsinger (1975) had facilitated a myriad of undesirable acts, including trespassing, vandalism, pothunting, bat disturbance, and visitation by ill-prepared individuals. Both the cave resources and landowner relations for responsible cavers suffered. Shortly after the publication of Holsinger (1975), the Virginia Speleological Survey decided to never again publish cave location information, or otherwise make such information available to the general public.

In 2000, the Data Committee of the Virginia Cave Board dissolved and the Board officially delegated maintenance of the Significant Cave List to the Virginia Speleological Survey, which in practice had been the case for quite some time because of crossover between Cave Board Membership and the Survey Directorate. A major concern of the Survey to this point was the security of cave entrance location information. When Natural Heritage staff began to work on development of cave conservation sites in 2002, it became apparent that access to the Virginia Speleological Survey database was essential for development of meaningful conservation sites. Several months of negotiations resulted in the establishment in October of 2002 of a data sharing agreement between the Survey and the Natural Heritage Program. The main provisions of the agreement are:

- The Natural Heritage Program will no longer maintain an electronic database of cave entrance locations.
- The Virginia Speleological Survey will work with Natural Heritage Staff to create polygons representing surface overlays of designated significant caves and other caves with natural heritage resources. These polygons will be used to represent cave locations in the internal electronic databases of the Natural Heritage Program, replacing previous point entrance locations. These polygons will not be shared externally without the written permission of the Survey.
- Natural Heritage Staff will work with the Survey to assemble and digitize information to establish conservation sites. These conservation sites will be shared with other agencies, organizations, companies, or individuals in the interest of cave and karst protection.
- Prior to establishment of a conservation site, caves will represented for conservation screening by "Surrogate Conservation Sites" – 3 km radius circles enclosing cave entrances, with centers offset up to 2 kilometers from cave entrance locations.
- The word "cave" would be removed from the "sitename" field in electronic databases, so that their names do not identify the presence of a cave.
- As resources allow, Natural Heritage will provide maps and digital coverage of significant cave information to the Virginia Cave Board and the Survey.
- The Survey will update Natural Heritage when caves are added to the Significant Cave List, or when updated information about significant caves are determined, subject to restriction placed on the data when acquired by Survey.
- Unless restricted by the landowner, Natural Heritage staff will provide Survey with any cave-related data generated in house, including cave locations; cave surveys and maps; biological inventories; updates on ownership, condition of the cave, and conservation status; and the results of hydrological information.
- Natural Heritage staff and the Survey will continue to work together to review projects for possible impacts to caves.

Implementation of the data sharing agreement necessitated both additional funding and staffing for the Natural Heritage Karst Program. Major sponsors of conservation site development for caves to date include the Cave Conservancy of the Virginias, the Virginia Department of Transportation, and the Virginia Land Conservation Fund. Additional staffing needs have been met through partnership with Virginia Tech and the hiring of temporary employees. All individuals working on the project have significant experience working with caves and karst.

Conservation site designs for caves are based on numerous factors including hydrology, geology, topography, extent of the cave passage, and security of cave entrance locations. For caves that are hydrologically significant (that is, a stream or phreatic water exists in the cave), conservation sites encompass the watershed contributing to the cave. Because karst systems commonly bypass surface drainage divides, watershed delineations rely heavily on new and prior tracer dye studies. In some cases, geologic formation boundaries are inferred to be hydrologic barriers.

For caves that are not hydrologically significant, conservation sites are designated as the ground area that covers all of the underlying cave passages, or the cave "footprint," plus an additional buffer. The shape and extent of the buffer depends upon a variety of case specific factors, including local geology, proximity of surface karst features, and protection of entrance location security.

An example of conservation site development — The Central Lee County, Virginia, Karst

The karst of central Lee County, Virginia, as shown in Figure 1, contains 19 designated significant caves. An additional four caves are homes to other natural heritage resources. Prior to development of conservation sites, projects were screened from proximity to these caves, and then analysis was performed to check for potential impacts. Furthermore, these datapoints placed the cave entrance location information at risk should they fall into the wrong hands.

Figure 2 shows the polygons developed cooperatively by the Natural Heritage Program and the VSS, for internal use only by Natural Heritage staff. Note the presence of 3 significant caves not previously tracked by the state, which could now be better protected through project review. In addition, the development of these polygons revealed incorrect locations statewide within the Natural Heritage database. Also shown in Figure 2 is a pair of karst springs not associated with specific caves, yet from which natural heritage resources, in this case globally rare and legally protected invertebrates, have been collected. Such springs, although not caves per se, require the same methodology for development of conservation sites.

Figure 3 shows the conservation sites designed as protection tools for these 23 caves and two springs. Two of these caves have not yet been incorporated in conservation sites. Also shown are

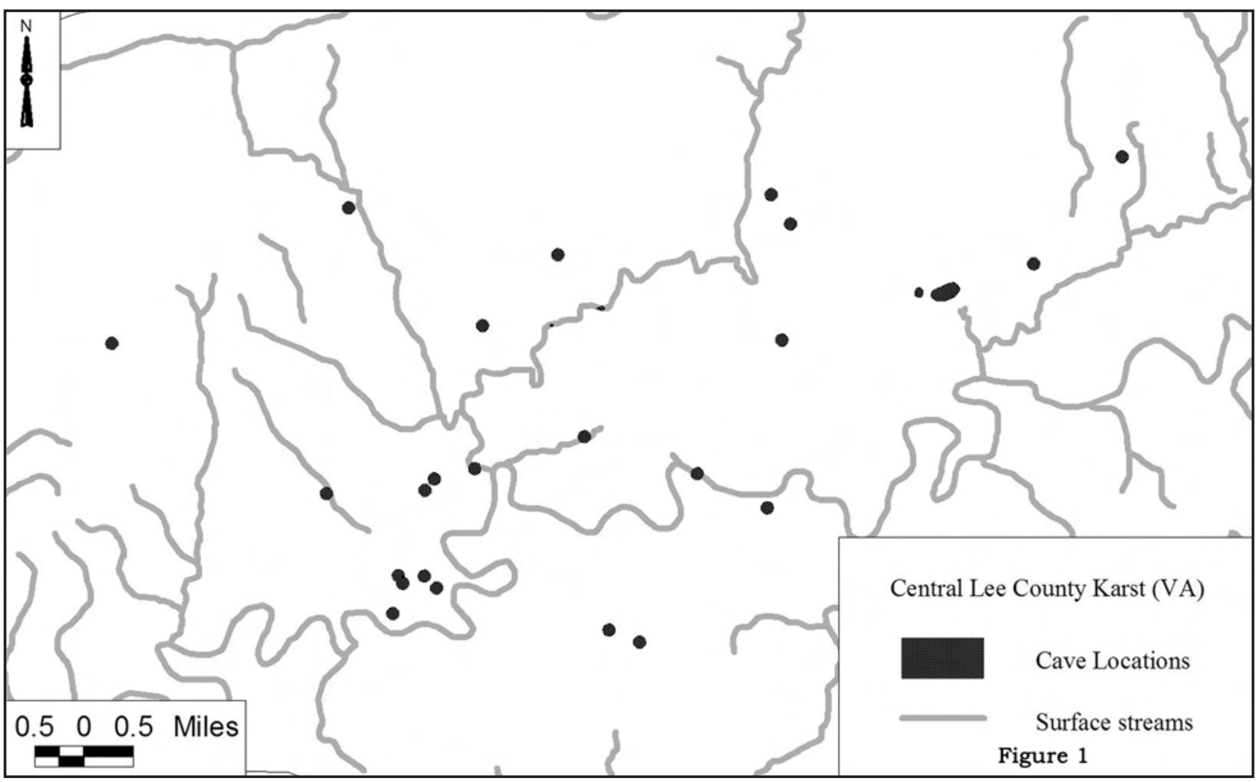

Figure 1

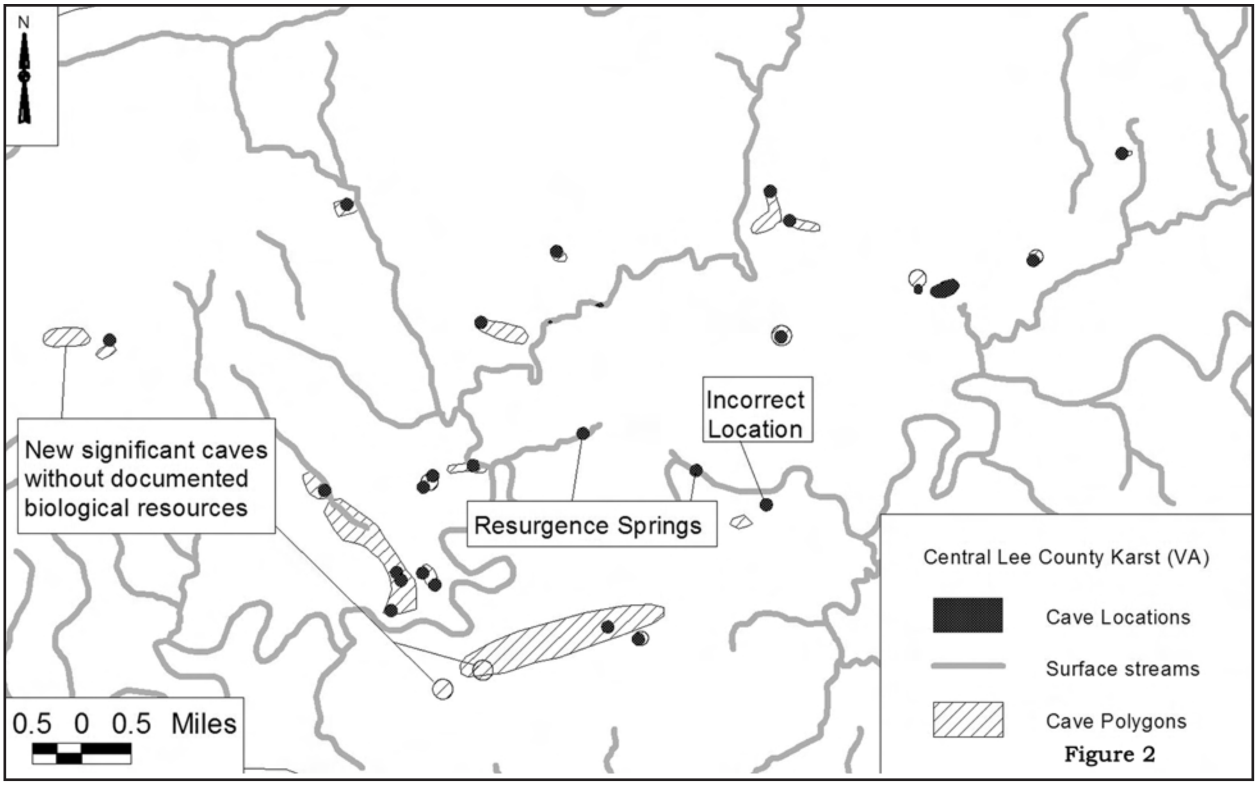

Figure 2

vectors representing the results of dye trace studies, which form the basis for many of the conservation sites. In general, the conservation site for a cave of hydrological significance is the buffered footprint of the cave plus its watershed. In cases where water entering the subsurface diverges, conservation sites may overlap as shown in the figure. In other cases, dye traces may pass beneath a site that lacks hydrological significance, and thus not be relevant to site delineation.

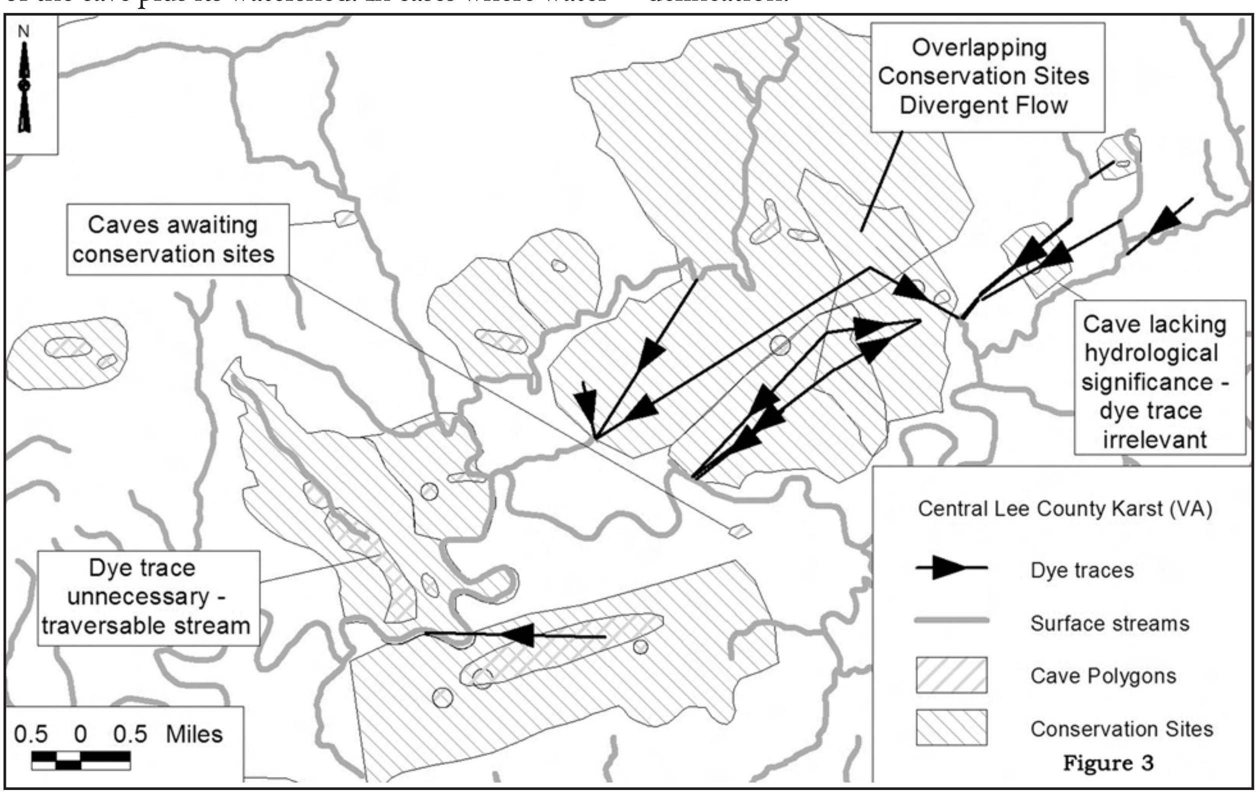

Figure 3

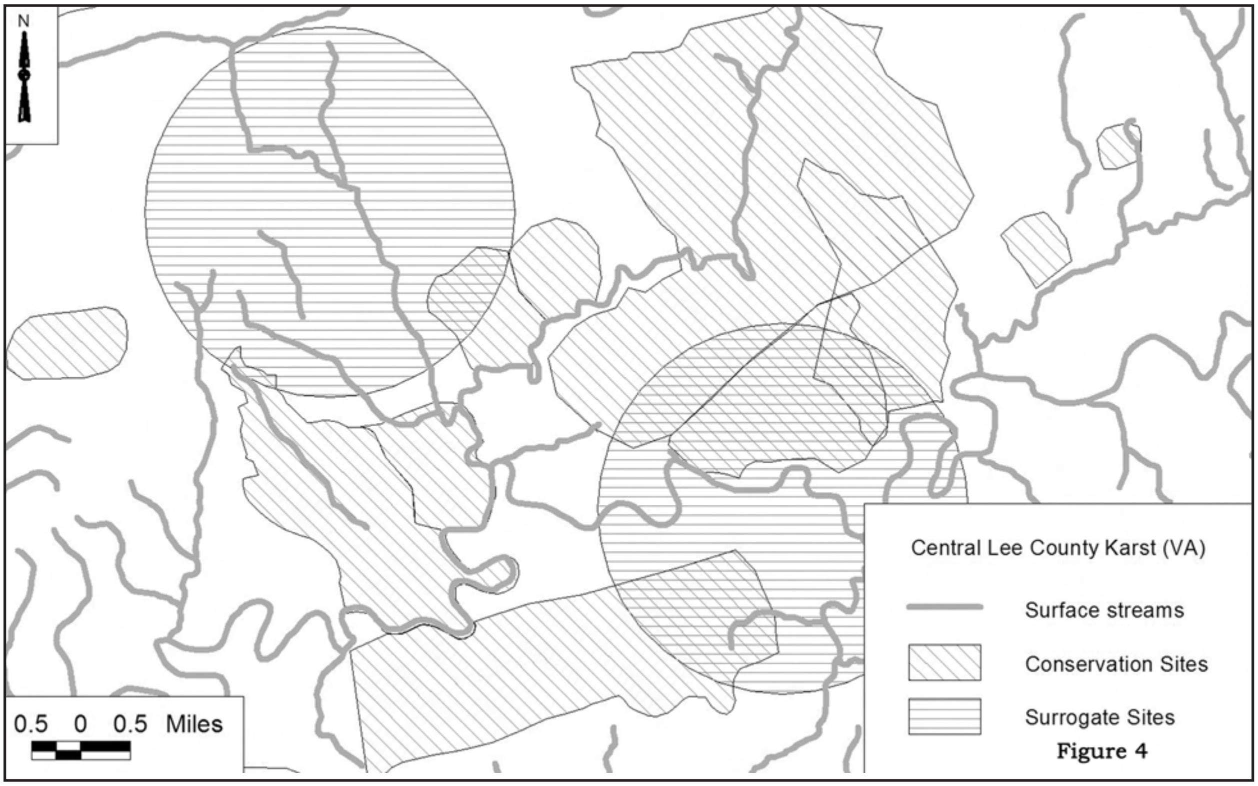

Figure 4 shows the current cave screening coverage used during project review for central Lee County. The two, six-kilometer-diameter circles are surrogate conservation sites that will be replaced by conservation sites when design is complete, and are much larger than most conservation sites.

Progress to Date

At present, the Natural Heritage Program internal database contains 381 polygons representing 410 caves, including the 362 designated as significant under the Virginia Cave Protection Act. The smallest cave polygon is just under 3 acres, the largest 1,100 acres, and the median 40 acres. These polygons have completely replaced point locations in the Natural Heritage electronic geographical database (GIS).

Design of conservation sites for these caves and their associated biological resources is well underway. To date, 72 conservation sites have been designed encompassing 163 of these caves, including 151 designated as significant. The minimum size cave conservation site is 80 acres, the maximum 9,000 acres, with a median of 695 acres. Ninety percent of the conservation sites exceed 200 acres.

The remaining approximately 250 caves are represented for project review by 200 surrogate conservation sites. The size of a surrogate site is 6,900 acres, larger than all but four of the conservation sites. Ninety percent of the conservation sites are less than half of the size of a surrogate site. Replacing these surrogate sites with realistic conservation sites is a top priority of the Natural Heritage Program, in order to better and more efficiently protect these resources.

Biodiversity significance

The caves and karst of Virginia are home to a rich and varied invertebrate cave fauna, as well as eight bat species. Virginia's caves include about 650 element occurrences of natural heritage resources, mostly rare invertebrates, including about 25% of rare invertebrates statewide. Many undescribed species are present, some of which are not yet tracked in the Natural Heritage database. New species and new occurrences of known species are found on a regular basis.

Biodiversity values (B-ranks) are assigned to all conservation sites in an attempt to quantify this significance. Appendix A (after Wilson and Tuberville, 2003) illustrates the methodology behind B-rank determination, developed by Natureserve™ and used by natural heritage programs throughout

Table 3. Biodiversity significance of Virginia's Cave Conservation Sites

Biodiversity Rank	Conservation sites	Surrogate Sites
B1	16	17
B2	20	43
B3	16	29
B4	7	32
B5	13	79

Most B5 sites represent significant caves or groups of caves where little to no biological inventory work has been performed.

North America. Ranks range from B1 (outstanding significance) to B5 (general significance).

Table 3 summarizes the biodiversity ranking of Virginia's cave conservation sites. Of the 72 conservation sites, half rank B2 or higher. An addition 30% of the surrogate sites (60) also rank B2 or higher. Because of the lack of biological surveys for many of the significant caves, the true degree of biodiversity may be even greater.

Sites are also coded for the presence of legally protected species. Of the 72 cave conservation sites, 24 include species with legal status. In addition, 30 of the 200 surrogate conservation sites include legally protected species.

Conclusions

The project review office in the Virginia Natural Heritage Program screens hundreds of projects each year for potential impacts to caves, karst, and associated biological resources. The numerous success stories arising from this process will be the topic of future papers. Successful implementation of this process depends on a partnership between the Natural Heritage Program, the Virginia Speleological Survey, and the Virginia Cave Board. Working together, these organizations have found a way to screen cave resources for potential impact from development projects without compromising data security. Caves are protected by screening proposed projects against conservation sites, then coordinating with the Virginia Karst Program, the Virginia Speleological Survey, the Cave Board, and appropriate regulatory agencies. To date, 40% of Virginia's caves containing natural heritage resources are incorporated into conservation sites. The remaining 60% are represented by larger, surrogate sites until conservation sites can be designed.

Acknowledgements

The authors would like to acknowledge the Virginia Natural Heritage Program Data Management staff and the Virginia Speleological Survey Directors for working to establish this process. Special thanks go to the Cave Conservancy of the Virginias, the Virginia Department of Transportation, and the Virginia Land Conservation Fund for financial support of conservation site development for Virginia's significant caves.

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APPENDIX A

Conservation Sites Ranking (after Wilson and Tuberville, 2003)

Brank is a rating of the significance of the conservation site based on presence and number of natural heritage resources; on a scale of 1-5, 1 being most significant. Sites are also coded to reflect the presence/absence of federally/state listed species:

Conservation Site Ranks
B1 – Outstanding significance
B2 – Very High significance
B3 – High significance
B4 – Moderate significance
B5 - Of general Biodiversity significance

Legal Status of
FL – Federally listed species present
SL – State listed species present
NL – No listed species present

Examples: A B1NL site is of outstanding significance with no listed species present.
A B4FL site is of moderate significance with a federally listed species present.

Global and State Ranks (defined on next page)

Element Occurrence Ranks		**G2**	**G3**	**G4/S1**	**G5/S1**	**G4 or G5 & S2**	G4 or G5 & S3	**Any Community**
A		B2	B2	B4	B4	B4	B5	B3
4 or more with A rank		B1	B2	B3	B3	B4	B4	B2
B		B2	B3	B4	B4	B5	B5	B4
4 or more with B rank		B1	B2	B3	B3	B4	B5	B3
C		B3	B4	B5	B5	B5		B5
4 or more with C rank		B2	B3	B5	B5	B5		
D		B3	B5	B5	B5	B5		

- EO ranks not yet assigned, "E", or "H" ranked treated as "C" rank for ranking of cave-associated populations.
- Borderline EO ranks are treated as the lower of the two (i.e. AB=B)
- Borderline G- and S- ranks are treated as the higher of the two (i.e. G1G2=G1)
- Range ranks are treated as the middle rank (i.e. G1G3=G2)
- Question marks should be ignored
- Ranks with T are treated as next lower G-rank (G4T1=G2)
- **B1** rank is assigned to sites that include single-site endemics
- Most outstanding EO of any community element is assigned a rank of **B2**

Definitions of Abbreviations Used on Natural Heritage Resource Lists of the Virginia Department of Conservation and Recreation

Natural Heritage State Ranks

The following ranks are used by the Virginia Department of Conservation and Recreation to set protection priorities for natural heritage resources. Natural Heritage Resources, or "NHR's," are rare plant and animal species, rare and exemplary natural communities, and significant geologic features. The criterion for ranking NHR's is the number of populations or occurrences, i.e. the number of known distinct localities; the number of individuals in existence at each locality or, if a highly mobile organism (e.g., sea turtles, many birds, and butterflies), the total number of individuals; the quality of the occurrences, the number of protected occurrences; and threats.

S1 - Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state. Typically 5 or fewer populations or occurrences, or very few remaining individuals (<1000).

S2 - Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state. Typically 6 to 20 populations or occurrences or few remaining individuals (1,000 to 3,000).

S3 - Vulnerable in the state either because rare and uncommon, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically having 21 to 100 populations or occurrences (1,000 to 3,000 individuals).

S4 - Apparently secure; Uncommon but not rare, and usually widespread in the state. Possible cause of long-term concern. Usually having >100 populations or occurrences and more than 10,000 individuals.

S5 - Secure; Common, widespread and abundant in the state. Essentially ineradicable under present conditions, typically having considerably more than 100 populations or occurrences and more than 10,000 individuals.

S#B - Breeding status of an animal within the state

S#N - Non-breeding status of animal within the state. Usually applied to winter resident species.

S#? - Inexact or uncertain numeric rank.

SH - Possibly extirpated (Historical). Historically known from the state, but not verified for an extended period, usually > 15 years; this rank is used primarily when inventory has been attempted recently.

S#S# - Range rank; A numeric range rank, (e.g. S2S3) is used to indicate the range of uncertainty about the exact status of the element. Ranges cannot skip more than one rank.

SU - Unrankable; Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.

SNR - Unranked; state rank not yet assessed.

SX - Presumed extirpated from the state. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.

SNA - A conservation status rank is not applicable because the element is not a suitable target for conservation activities.

Natural Heritage Global Ranks are similar, but refer to a species' rarity throughout its total range. Global ranks are denoted with a "G" followed by a character. Note GX means the element is presumed extinct throughout its range. A "Q" in a rank indicates that a taxonomic question concerning that species exists. Ranks for subspecies are denoted with a "T". The global and state ranks combined (e.g. G2/S1) give an instant grasp of a species' known rarity. **These ranks should not be interpreted as legal designations.**

FEDERAL LEGAL STATUS

The Division of Natural Heritage uses the standard abbreviations for Federal endangerment developed by the U.S. Fish and Wildlife Service, Division of Endangered Species and Habitat Conservation.

LE - Listed Endangered
LT - Listed Threatened
PE - Proposed Endangered

PT - Proposed Threatened
C - Candidate (formerly C1 - Candidate category 1)
E(S/A) - treat as endangered because of similarity of appearance
T(S/A) - treat as threatened because of similarity of appearance
SOC - Species of Concern species that merit special concern (**not a regulatory category**)
NL – no federal legal status

STATE LEGAL STATUS
The Division of Natural Heritage uses similar abbreviations for State endangerment.

LE - Listed Endangered
PE - Proposed Endangered
SC - Special Concern - animals that merit special concern according to VDGIF (not a regulatory category)
LT - Listed Threatened
PT - Proposed Threatened
C - Candidate
NL - no state legal status

For information on the laws pertaining to threatened or endangered species, please contact:

U.S. Fish and Wildlife Service for all **FEDERALLY** listed species;
Department of Agriculture and Consumer Services, Plant Protection Bureau for **STATE** listed plants and insects
Department of Game and Inland Fisheries for all other **STATE** listed animals

THINKING ABOUT KARST AND WORLD HERITAGE

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Abstract

Karst is already well represented on the World Heritage Register, but there are still many gaps. The World Heritage Committee is looking for a framework defining categories of natural heritage so that priorities can be set in order to determine the comprehensiveness and credibility of the registered sites. This paper is an early step in establishing appropriate categories for the classification of karst. It lists proposed categories, then lists the existing World Heritage sites in each and finally provides examples of sites which might extend the comprehensiveness of the total list. Comments and suggestions are sought on the categories suggested, not the sites, as these are for illustrative purposes only at this stage.

KARST MANAGEMENT IN BRITISH COLUMBIA: THE TRANSITION TO A RESULTS-BASED FOREST PRACTICES FRAMEWORK AND THE LEGALLY SUPPORTED PRACTICE REQUIREMENTS FOR KARST RESOURCE FEATURES

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Abstract

The release of karst inventory standards and vulnerability assessment procedures in 2001, and best practice recommendations for forestry operations on karst in 2003, has laid the groundwork for more comprehensive management of karst resources in British Columbia's forests. In January 2004, the British Columbia Government introduced the Forest and Range Practices Act, a new results-based regulatory framework for forest practices. The act will have profound implications for karst management in British Columbia. Draft government orders made pursuant to regulations under the act have identified categories of karst features and karst terrain that would be legally subject to a practice requirement of not damaging or rendering the resource feature ineffective when conducting a primary forest activity. Under these proposed orders and the Forest and Range Practices Act, it is the responsibility of forest companies to recognize and assess the various categories of karst resource features, and to prescribe the appropriate forest practices for them, using professional advice when needed.

Introduction

In January 2004, the Forest and Range Practices Act was introduced in British Columbia to streamline regulatory forest management requirements and improve the competitiveness of the provincial forest and range sectors, while at the same time maintaining high environmental standards. The the Forest and Range Practices Act is a results-based legislative and regulatory framework whereby the government establishes objectives for resource values, and forest companies (licensees) prepare results and/or strategies that must be consistent with those objectives.[1] The development of appropriate results and strategies is left to the professional judgment and discretion of the licensee; however, the government retains the responsibility for reviewing and approving licensees' operational plans. The focus of the Forest and Range Practices Act is on "end results" rather than prescriptive forest practices. The act replaces the more prescriptive Forest Practices Code, which has guided forest management in British Columbia since 1995.

This paper presents an overview of British Columbia's new results-based approach to forest practices and how it relates to the management of karst resources in British Columbia. The recently proposed use of legally supported practice requirements, and other legal and non-legal options for karst management under the Forest and Range Practices Act, are discussed. The paper also addresses related issues such as professional reliance, the evaluation and monitoring of karst resources under the Forest and Range Practices Act, the role of the Forest Practices Board, certification and self-regulation, and the next steps for karst management in British Columbia.

1 A licensee for this purpose means a forest agreement holder; a holder of an agreement under the Forest Act.

Background to Karst Management in British Columbia

The westernmost of Canada's ten provinces, British Columbia borders the Pacific Ocean, and the states of Alaska and Washington. The province is nearly one million square kilometers (or 621,371 square miles) in area and is significantly larger than the state of Texas for comparison purposes.

British Columbia is Canada's most ecologically diverse province and home to some of the nation's finest karst resources. Approximately 10% of the province is underlain by soluble bedrock that has the potential to form karst. Extensive areas of carbonate bedrock and karst occur within the Rocky Mountains in alpine and sub-alpine settings. Karst is also known in many other areas of inland British Columbia: in the Northwest (Stikine, Nakina, and Taku Rivers), the Southeast (Nelson area and Glacier National Park), the Northeast (Chetwynd and Prince George areas) and in South Central British

Columbia (Marble Range).

Some of the best-developed and most significant karst areas in British Columbia occur along the Pacific Coast, particularly Vancouver Island and the Queen Charlotte Islands/Haida Gwaii. This karst is distinctive because of its unique association with the coastal temperate rainforest biome.[2] Large mature trees, diverse plant and animal communities, highly productive aquatic systems, well-developed subsurface drainage, and extensive surface karst often characterize these coastal karst ecosystems and underlying cave resources. Most of the issues related to karst management in British Columbia have focused on these coastal areas, since they tend to be highly productive forest sites.

More than 90% of karst resources in British Columbia are publicly owned.[3] This means that the vast majority of the forests and the karst are administered and regulated by government on behalf of all British Columbians.

Under the Canadian Constitution, the provinces are responsible for most aspects of natural resource management, which by default includes karst. However, karst is rarely, if ever, addressed explicitly in any provincial legislation. There is currently no specific law or regulation governing the protection and conservation of karst resources in British Columbia. The British Columbia *Park Act* can provide legal protection for karst, but this has effect only where karst resources occur in parks and other protected areas. The British Columbia *Heritage Conservation Act* can be applied wherever specific archeological and cultural heritage resource values are known to occur in relationship with karst. The British Columbia *Wildlife Act* has some limited application as well. Historically, British Columbia government agencies other than the Ministry of Forests and Range and its predecessors have not played a significant role in karst management. The Ministry of Forests and Range has primary responsibility for managing karst resources in British Columbia forests outside of protected areas. Managing karst in British Columbia has therefore been largely integrated with managing forest lands.

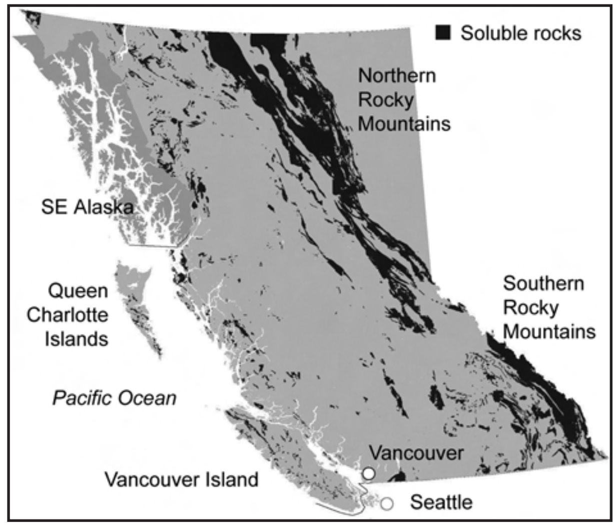


Figure 1: Distribution of Soluble Rocks in British Columbia.

Karst management in British Columbia forests was initially shaped by concerns for the protection and conservation of specific caves. In recent years, however, there was a significant policy shift to a management strategy that considered both the surface and subsurface elements of a karst system. The end result was that British Columbia adopted a non-legally supported ecosystem approach to the management of karst and cave resources. This approach to managing karst resources was embodied within a series of significant government initiatives. In 2000, the British Columbia Government released *A Preliminary Discussion of Karst Inventory Systems and Principles for British Columbia* (Stokes and Griffiths 2000), which proposed a scientific framework for developing a standardized inventory system for karst ecosystems in British Columbia. The Karst Inventory Systems and Principles report led to the development of provincial standards (Resources Information Standards Committee) for conducting karst inventories, which were initially released in 2001 and revised in 2003: *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003). In 2003, the government also released the *Karst Management Handbook for British Columbia* (MOF 2003), which provides recommended best management practices for forestry operations on karst terrain. Finally, in 2004, the Ministry of

2 The major tree species here are western hemlock and amabilis fir, with some western red cedar, yellow cedar and Sitka spruce. This biome is essentially the coastal western hemlock biogeoclimatic zone.

3 There is a larger than average proportion of privately owned land on Vancouver Island, and to the extent that this land encompasses karst there is less regulation of the resource.

Forests initiated the development of monitoring and effectiveness evaluation indicators and protocols for karst resources under the Forest and Range Practices Act Resource Evaluation Program.

The management approach described above recognizes the four fundamental environmental components to be managed in a karst ecosystem — air, water, land and biota — and takes into account the fact that the three-dimensional nature of karst causes it to function quite differently from other landforms, presenting unique challenges to land management. In particular, the approach recognizes the potential for karst systems to transport air, water, nutrients, soil, and pollutants into and through underground environments. This potential is considered carefully when developing and implementing management strategies for karst landscapes. The overall management strategy subscribes to the following key principles:

- Focuses on protecting the integrity of karst systems, including individual surface karst features, caves and the broader karst landscape.
- Independence of scale (for example, micro-relief karst features, such as karren exposures, are managed along with larger scale components such as complex cave systems).
- Not all karst features need to be found or known in order to manage the karst system.
- Subsurface karst resources are to be managed through appropriate forest practices applied on the surface, utilizing a total karst catchment approach.
- Contributing non-karst portions of delineated karst catchment areas should also be considered.

The the Forest and Range Practices Act

To improve the competitiveness of the provincial forest and range sectors and reduce administrative requirements, the British Columbia Government introduced the Forest and Range Practices Act and associated regulations in January 2004. Over a three-year transition period (January 31, 2004–December 31, 2006), the Forest and Range Practices Act replaces the 1995 Forest Practices Code, which was viewed by many in industry and government as cumbersome, costly, and inflexible.

One of the primary goals of the act is to focus on the end results of forest practices rather than prescriptive requirements. Under this new approach to forest management, licensees are responsible for developing plans containing results and strategies consistent with government objectives for managing 11 resource values identified under the act: soils, visual quality, timber, forage and associated plant communities, water, fish (riparian), wildlife, biodiversity, recreation resources, resource features (including karst as a subset), and cultural heritage resources. Some resource values under the Forest and Range Practices Act already have objectives established by government, in which case licensees are required to address those resource values in their plans.

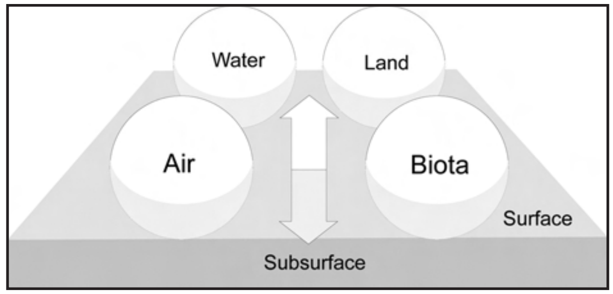


Figure 2: The Four Fundamental Environmental States and the Three-dimensional Nature of Karst.

This new results-based regime aims to reduce the complexity of the legislation and regulations, and lower costs to both industry and government. Maintaining environmental standards is an accompanying goal. The streamlined the Forest and Range Practices Act and regulations, and simplified legal policy framework, are to rely on a science-based approach to the management of natural resources, including karst.

The maximum fines that apply on conviction of an offence under the Forest and Range Practices Act range from $5,000 to $1,000,000 and imprisonment from six months to three years. For example, a person carrying out forest practices that result in damage to the environment can be fined up to $1 million. The maximum fine doubles for a person found liable on a second or subsequent conviction for the same offence.

Karst Management under the Forest and Range Practices Act and its Regulations

Practice Requirements for the Forest and Range Practices Act

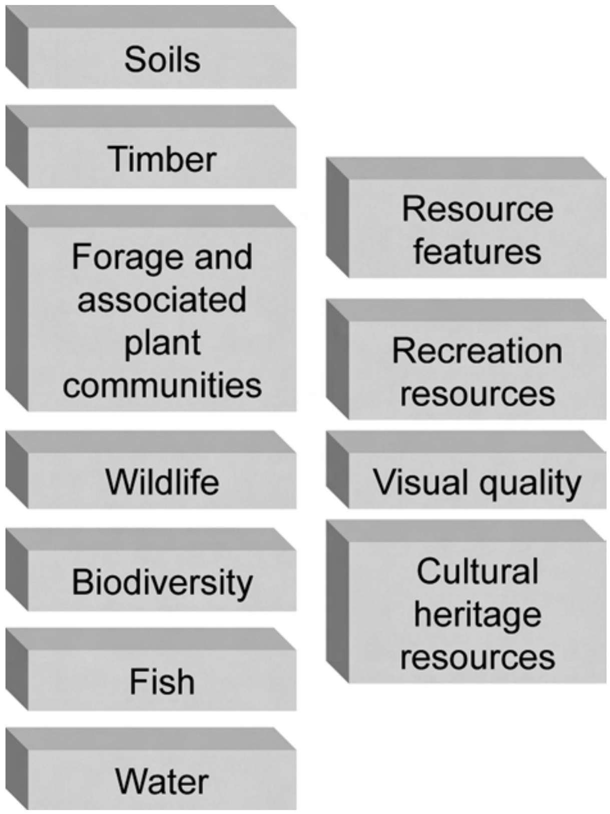


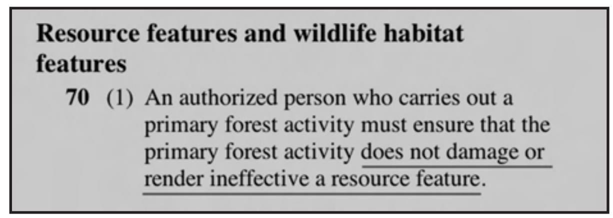
Figure 3: the Forest and Range Practices Act's 11 Resource Values to Manage and Protect.

Karst is not one of the 11 resource values identified under the Forest and Range Practices Act; it is a subset of resource features, which can also include range developments, public land used for research or experimental purposes, permanent snow sampling sites, Aboriginal traditional use sites, and recreation resources (for example, sites, trails, features).

There are two Forest and Range Practices Act regulations that can potentially impact the management of karst resources in British Columbia: the Government Actions Regulation and the Forest Planning and Practices Regulation. Section 5(1) of the Government Actions Regulation provides for identifying "a surface or subsurface element of a karst system" as a "resource feature." This specific recognition for karst resources as a resource feature in law is unprecedented in British Columbia, it is not found in any prior legislation.

Resource features are are "established" by a ministerial order. Resource features identified by such orders, including surface or subsurface elements of a karst system, must meet four tests before the order can proceed:

1. The order must be consistent with established objectives, such as existing land-use objectives, other objectives set by government, or objectives established under the Forest and Range Practices Act or the regulations.
2. The order must not unduly reduce timber supply.
3. The benefits of the order must outweigh any material adverse effects on a forest agreement holder, and any constraints on the ability of an agreement holder to exercise rights granted under the agreement.
4. The resource feature must require special management that is not otherwise provided for in provincial legislation.


Resource features and wildlife habitat features

70 (1) An authorized person who carries out a primary forest activity must ensure that the primary forest activity does not damage or render ineffective a resource feature.

Figure 4: Section 5(1) of the Government Actions Regulation.

Surface or subsurface elements of a karst system can be legally established as resource features by type or category, and may be restricted to a specified geographic location. All resource features previously established under the Forest Practices Code continue to be recognized as resource features under the Forest and Range Practices Act.

According to the Government Actions Regulation, an order must be sufficiently specific "to enable a person affected by it to identify the resource feature in the ordinary course of carrying out forest practices or range practices." Thus, a category or type of readily recognizable karst feature or karst terrain could be established by order as a resource feature. The precise outer boundaries of individual identified karst elements need not be specified in the order.

Opportunities for review and comment are provided to licensees that may be impacted by the establishment of resource features by order. There is also a legal provision not to disclose the precise location of a resource feature in an order if there is reason to believe that the resource feature could be subject to damage or disturbance if the location

Table 1: Milestones in Karst Management for British Columbia (1997-2005)

Year	Initiatives
1997	Karst inventory system and management practice projects initiated Karst poster and booklet
1998	Reconnaissance-scale karst potential mapping for British Columbia initiated
1999	Reconnaissance-scale karst potential mapping for British Columbia completed
2000	*A Preliminary Discussion of Karst Inventory Systems and Principles for British Columbia* published Field testing of karst inventory and vulnerability assessment procedures begins
2001	Version 1 of *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* released
2002	Training materials developed and Karst Field Assessment training course piloted Timber supply impact assessments completed
2003	Version 2 of *Karst Inventory Standards and Vulnerability Assessment Procedures* released *Karst Management Handbook for British Columbia* released *Note to the Field* released Web training course launched
2004	New results-based regulatory regime (the Forest and Range Practices Act) transition Karst indicators and monitoring protocols developed
2005	Field testing of karst indicators and monitoring protocols Draft the Government Actions Regulation orders under the Forest and Range Practices Act identifying karst resource features

of the resource feature is disclosed. Licensees may be prohibited from disclosing the location of the feature, or restricted as to whom they disclose the location of the feature to. This would have potential applications to sensitive caves or other karst features.

The legal practice requirement for resource features established by order is specified in Section 70(1) of the Forest Planning and Practices Regulation. Once established as a resource feature, the practice requirement specifies that primary forest activities (harvesting, road work and silviculture) must not damage the resource feature or render the feature ineffective.

The best management practices for karst as recommended in the *Karst Management Handbook for British Columbia* provide forest practices that can be used for both specific karst features and broad karst landscapes.[4] As the Forest and Range Practices Act approach is based on specifying outcomes as opposed to specific practices for karst, licensees can set out to meet the practice requirement for karst resource features established by an order (as outlined above) by utilizing recommendations from the Karst Management Handbook, or by em-

4 As an example, the Karst management Handbook recommends a two-tree-length reserve (to maintain microclimatic conditions) and a management zone (to protect the reserve from windthrow) for sinkholes with distinct microclimates.

ploying new alternative strategies. As licensees and operators gain more knowledge and experience, they are expected to become more innovative karst managers, and less likely to rely solely on the Karst Management Handbook.

Resource features

5 (1) Subject to subsection (2), the minister responsible for the *Forest Act* by order may identify one or more of the following as resource features in relation to a specified area:

(a) a surface or subsurface element of a karst system

Figure 5: Section 70(1) of the Forest Planning and Practices Regulation.

The Forest and Range Practices Act Objectives and Strategies

As noted earlier, some, but not all, the Forest and Range Practices Act resource values have objectives established by government. For those resource values with established government objectives, licensees must prepare Forest Stewardship Plans that identify results and/or strategies consistent with meeting those objectives. Objectives for the Forest and Range Practices Act resource values can include: land-use objectives (for example, objectives established under regional planning processes), objectives previously set by government (for example, objectives rolled over from the Forest Practices Code), and objectives set by government under the Forest and Range Practices Act and associated regulations. Examples of resource values with objectives set by government under the Forest and Range Practices Act and the regulations include soils, timber, water, fish, wildlife, biodiversity, and cultural heritage resources.

Resource features have no specific objectives set by government under the Forest and Range Practices Act and the regulations at the present time. Karst resources that might be established by order as resource features are not currently required to be included in Forest Stewardship Plans, as there are no existing land-use objectives or other legal objectives established by government for karst.[5] If resource features are established by order, they are managed instead by the legal practice requirements specified in the Forest Planning and Practices Regulation.

If land-use objectives for karst resources were to be legally established from approved land-use plans previously established under the Forest Practices Code, they can override any the Forest and Range Practices Act requirements for karst if the land-use objectives conflicted with the Forest and Range Practices Act requirements. In the land-use planning process, objectives can be set for resource values that are not listed under the Forest and Range Practices Act and the objectives are not subject to the Forest and Range Practices Act timber supply impact policy.

The Vancouver Island Land Use Plan has been established as a higher-level plan under the former *Forest Practices Code of British Columbia Act*. The summary of this plan offers the following karst management strategies for consideration:

- Paying particular attention to issues of forestry and cave/karst interaction, including karst geology, hydrology, soils, karst and cave biology, and cultural and recreational cave and karst features prior to forestry-related development within areas of high cave/karst occurrence or potential;
- Designing development activities in a manner which minimizes and/or mitigates impacts on sensitive cave/karst features and terrains;
- Managing cave/karst features and terrain in accordance with approved cave/karst guidelines. (Prov. of B.C. 2000)

The objectives for karst management described in the summary of the plan have not been legally established by a higher-level plan order. If established, however, the implementation of strategies and results to meet those objectives would become mandatory and form part of an approvable plan (that is, Forest Stewardship Plan).

Many regions of British Columbia where karst resources are known to occur have no approved higher-level plans and objectives.

There are important linkages between the Forest and Range Practices Act and land-use planning processes such as the new Sustainable Resource Management Plans. Sustainable Resource Management Planning is a provincial planning process for

5 The *Karst Management Handbook for British Columbia* outlines comprehensive management objectives for karst, but this provincial government document for karst is not legally supported.

public lands and natural resources in British Columbia. It incorporates various other planning processes, including those for landscape units, watersheds, local resource uses and coastal areas, all under one umbrella. The Sustainable Resource Management Plans can provide resource management direction (that is, objectives) needed for operational planning and Forest Stewardship Plans. If an Sustainable Resource Management Plans were to identify karst resources that required special management considerations (that is, additional protection), government may establish specific objectives for those karst resources that should be included in Forest Stewardship Plans (Prov. B.C. 2004). Sustainable Resource Management Plans also offer the possibility of implementing a total catchment approach to karst resource management and protection.

An option for the management of some karst resources under the Forest and Range Practices Act is to establish a feature or area as an interpretive forest site, recreation site, or recreation trail. This option is available only if the feature or area clearly has recreational value and is therefore not applicable to management of the majority of karst resources in British Columbia. Objectives for interpretive forest sites, recreation sites, and recreation trails can be established under Section 56 of the Forest and Range Practices Act. These objectives must be included in Forest Stewardship Plans, along with results and/or strategies for achieving the objectives.

Professional Reliance and the Forest and Range Practices Act

Professional reliance is heralded as one of the key components of the Forest and Range Practices Act, and is founded on the discretion and judgment of professional resource managers to design, prescribe, and assess appropriate measures to achieve specific forest resource objectives. A large part of professional reliance is the expectation that a professional will exercise due diligence — the same level of care that another professional would or ought to have exercised under the same circumstances.

No one professional body in British Columbia has sole jurisdiction over karst resources. Karst is a multidisciplinary field with a variety of professionals playing a potential role. Typically, two or more professionals representing different disciplines come together as a team (for example, a geoscientist, engineer, biologist, or a forester) with only one taking overall professional responsibility. the Forest and Range Practices Act is predicated on the principle that practitioners in their respective disciplines apply good judgment and act in the interest of the public and karst resources. It is therefore essential that these professionals have some level of karst competence, understand the limits of their competence, and know when to call in another professional to assist with a particular activity.

The conduct of professionals in British Columbia is governed by legislation, codes of ethics, and standards of practice applicable to each discipline. Professionals are accountable to their respective regulatory bodies in the fields of geoscience, engineering, forestry, biology, and agrology.

Holding professional foresters accountable for their actions under the Association of British Columbia Forest Professionals and the *Foresters Act* will be a key tool to curb any unprofessional practices including those affecting the protection of karst resources. However, as already noted, there is no single regulatory body dedicated to overseeing karst practices, and the existing regulatory bodies have yet to set standards for karst competence (for example, developing required skill sets). Since there is so much overlap in managing karst resources, it is expected that joint practice boards will eventually provide practice directives for karst.

The best management practices recommended in the Karst Management Handbook are an important professional reliance tool for professionals working in the karst field. Guidelines for personnel qualifications and training of personnel completing karst inventories in British Columbia are provided in the *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia*.

Evaluating the Management of Karst Resources Under the Forest and Range Practices Act

The Forest and Range Practices Act and its regulations place a much greater emphasis on monitoring and evaluating the outcomes of forest management. Under the Forest and Range Practices Act Resource Evaluation Program, a series of effectiveness indicators and monitoring protocols have been developed for assessing whether or not forest practices have adequately protected karst features and karst terrains.[6] These were refined in 2004 with the input of industry, government, and karst experts, and field tested in 2005. The questions and supporting indicators are based on definitions, assessment procedures and management objectives as outlined in the *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* and the *Karst Management Handbook for British Columbia*. Draft the Government Actions Regulation orders that are consistent with these provincial guidance documents for karst will further facilitate the application of the evaluation indicators and monitoring protocols.

The Forest and Range Practices Act Resource Evaluation Program will measure the success of the Forest and Range Practices Act in the sustainable management of resource values through ongoing monitoring and evaluation projects. The results of the program will be used to identify implementation issues regarding forest practices, policies and legislation, and promote the continuous improvement of forest practices in British Columbia.

As part of this program, the environmental indicators and monitoring protocols that were developed for karst resources will provide a means of determining if forest practices are successful in achieving the appropriate types and levels of karst management recommended in the Karst Management Handbook and any the Forest and Range Practices Act requirement for karst resource features identified by order.

The karst monitoring protocols will be used by the Ministry of Forests and Range, licensees, and other agencies (for example, the Forest Practices Board, compliance and enforcement agencies, and possibly even certification auditors) to assess the effectiveness of forest practices in the management of karst resources.

Since the evaluation of karst management practices is a new activity in British Columbia, the initial short-term goal will be to establish baseline information and general trends.

The Forest Practices Board of British Columbia

The Forest Practices Board is an independent forestry watchdog established by the British Columbia government. Its reports and findings are not subject to government approval prior to public release. Under the Forest Practices Code, the Board evaluated compliance with specific mandated forest practices, carried out special investigations, issued special reports, and responded to public complaints.

The Board has an important new role in the current results-based regime. Under the Forest and Range Practices Act, the Board will reduce the emphasis on assessing compliance and focus on the effectiveness of forest practices in achieving desired results. The Board will act as an independent auditor of the effectiveness of forest practices in the management of resource values, including karst resources that are legally established as resource features. It is also actively contributing to the transition to the results-based framework by working with all stakeholders to test monitoring and evaluation protocols. The Board is working cooperatively with the Ministry of Forests and Range Forest Practices Branch to develop the karst indicators, and is planning to test the karst monitoring protocols in a thematic audit.

Certification and Self-regulation

Some of the largest forest companies on the British Columbia coast have the capacity to voluntarily implement karst management strategies in the absence of any specific legal requirements. These voluntary efforts are often tied to corporate policies and objectives for environmental protection or sustainable forest management, or for obtaining market certification status.

Major licensees operating in karst currently employ a combination of certification schemes, and have developed both internal management and external auditing systems. Most have already achieved International Standards Organization (ISO) 14001 Environmental Management, Canadian Standards Association Sustainable Forest

6 The range of karst indicators covers the following four key categories: caves, surface karst features, sinking and losing streams, and broad karst landscape. Many of the indicators can be defined as routine indicators, which serve as a relatively quick and efficient assessment of the status of the karst resources with little or no analysis. Nevertheless, the indicators are considered to be responsive to karst management practices and measurable using scientifically and statistically based techniques.

Management, and/or the Sustainable Forestry Initiative certification for their operations.

While most large forest companies in British Columbia are certified under the ISO system, certification audits generally do not assess karst management performance specifically. If karst is managed as a resource feature that could be impacted by primary forest activities, and where those activities are deemed to be a significant environmental aspect of the licensee's operations, then the licensee's ISO 14001 environmental management system will normally have controls on the activities to prevent adverse impacts to the karst.

Development of the Government Actions Regulation Orders for Karst Resources: the Draft Order for the Campbell River Forest District

In May 2005, the Campbell River Forest District publicly announced the first proposed the Government Actions Regulation order identifying karst resource features.[7] This announcement was followed immediately by a 60-day public comment period and open houses. A final order was initially to have been made legally effective on or about August 15, 2005.

Pursuant to Section 5(1) of the Government Actions Regulation, the Campbell River Forest District draft order identified the following surface or subsurface elements of a karst system as categories of resource features wherever they are found within the forest district:

- Caves
- Surface karst features (including swallets and karst springs)
- Very high or high vulnerability karst terrain

To avoid a very lengthy order, the extensive roster of possible subcategories of "surface karst features," beyond the two specific examples, was purposely left out of the draft order.

The Campbell River Forest District draft order identified "very high or high vulnerability karst terrain" based on the *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia*, which defines the vulnerability of broad karst landscapes based on a four-step field procedure.[8]

Other Draft the Government Actions Regulation Orders for Karst Resources

Another two of British Columbia's eight coastal forest districts have since prepared draft the Government Actions Regulation orders for karst resources. The Queen Charlotte Islands Forest District followed with an order founded on the Campbell River Forest District model, which had been formulated with the help of karst experts. The Campbell River Forest District and Queen Charlotte Islands Forest District draft orders were based on wording consistent with existing provincial guidance documents for managing karst resources in British Columbia. However, a third draft order prepared by the South Island Forest District differed from the Campbell River Forest District and Queen Charlotte Islands Forest District draft orders.

In the South Island Forest District draft order there was a discrepancy between the draft order and the Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia vulnerability classification conventions, the latter being developed over a number of years with input from government agencies, industry, and qualified karst professionals and experts. The proposed vulnerability definition for karst terrain in the South Island Forest District draft order was based solely on feature densities and the presence of caves, oversimplifying the Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia procedure into one based on only a few vulnerability attributes. The South Island Forest District draft order defined high and very high vulnerability karst terrain based on the presence of more than ten karst "types" per hectare and a high

7 The Campbell River Forest District consists of 20,000 square kilometers of land, of which 42% is productive forest land, 22% alpine, swamp, and rock, 20% inaccessible forest and 16% park land. Significant karst features in the Campbell River Forest District include many of Canada's longest, deepest, and best decorated cave systems.

8 The procedure evaluates three major criteria: epikarst sensitivity, surface karst sensitivity, and subsurface karst potential. Other factors considered in assessing karst vulnerability include soil texture, overall karst roughness, and unique or unusual flora/fauna or habitats.

likelihood for caves. By reducing the defining attributes of high and very high vulnerability karst terrain to a feature density threshold and a high likelihood for caves, the South Island Forest District draft order addressed a narrower set of karst resources susceptible to primary forest activities (see Figure 6).

In addition, by not identifying "surface karst features" as a subcategory, the South Island Forest District draft order did not cover many features that can occur at different density levels in all types of karst terrain (low, moderate, high, and very high vulnerability). These features, such as springs, sinkholes, karst canyons, swallets, and the like, can also be significantly damaged or rendered ineffective by inappropriate forest practices. By contrast, the Campbell River Forest District and Queen Charlotte Islands Forest District draft orders identified surface karst features as a subcategory of karst resource features without density limitations.

The South Island Forest District draft order did identify karst caves as a specific subcategory of karst resource features. Consequently, such caves would be covered by the order regardless of the vulnerability classification of the karst terrain in which they occur.

Unresolved Draft Order Issues

In September 2005, the British Columbia Coast Forest Region struck a sub-committee with government and licensee representatives to develop guidance for consistent draft the Government Actions Regulation orders. While the Region has no power over the the Government Actions Regulation order process, the districts have agreed to see what the Coast Region Implementation Team sub-committee develops by way of consistent wording for these orders. The districts can then take this under advisement when developing their local orders. The Region plans to have the draft wording for the Government Actions Regulation orders sent out to karst experts before finalizing them for discretional use by the districts. The Coast Region Implementation Team sub-committee is scheduled to report on their work by the end of January 2006. (Reveley *pers. comm.* 2005)

It is anticipated that the following issues are likely to be considered during the development of regional guidance for drafting karst orders:

1. <u>Clarity and Precision in Defining Categories of Karst Resource Features</u>

An important unresolved issue is the question of clarity and precision in defining the categories of karst resource features identified by the the Government Actions Regulation orders.

The approach taken by the Campbell River Forest District and Queen Charlotte Islands Forest District draft orders was to leave out definitions that already exist in the established and accepted provincial guidance documents for karst — these could be referenced, if necessary, outside the orders. The draft orders simply identified the broader karst resource feature categories, whereas the many subcategories could be located and identified in the supporting provincial documents. Definitions for caves and other karst features, including the many possible subcategories of surface karst features, as well as karst vulnerability categories, are explicitly described in the Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia.

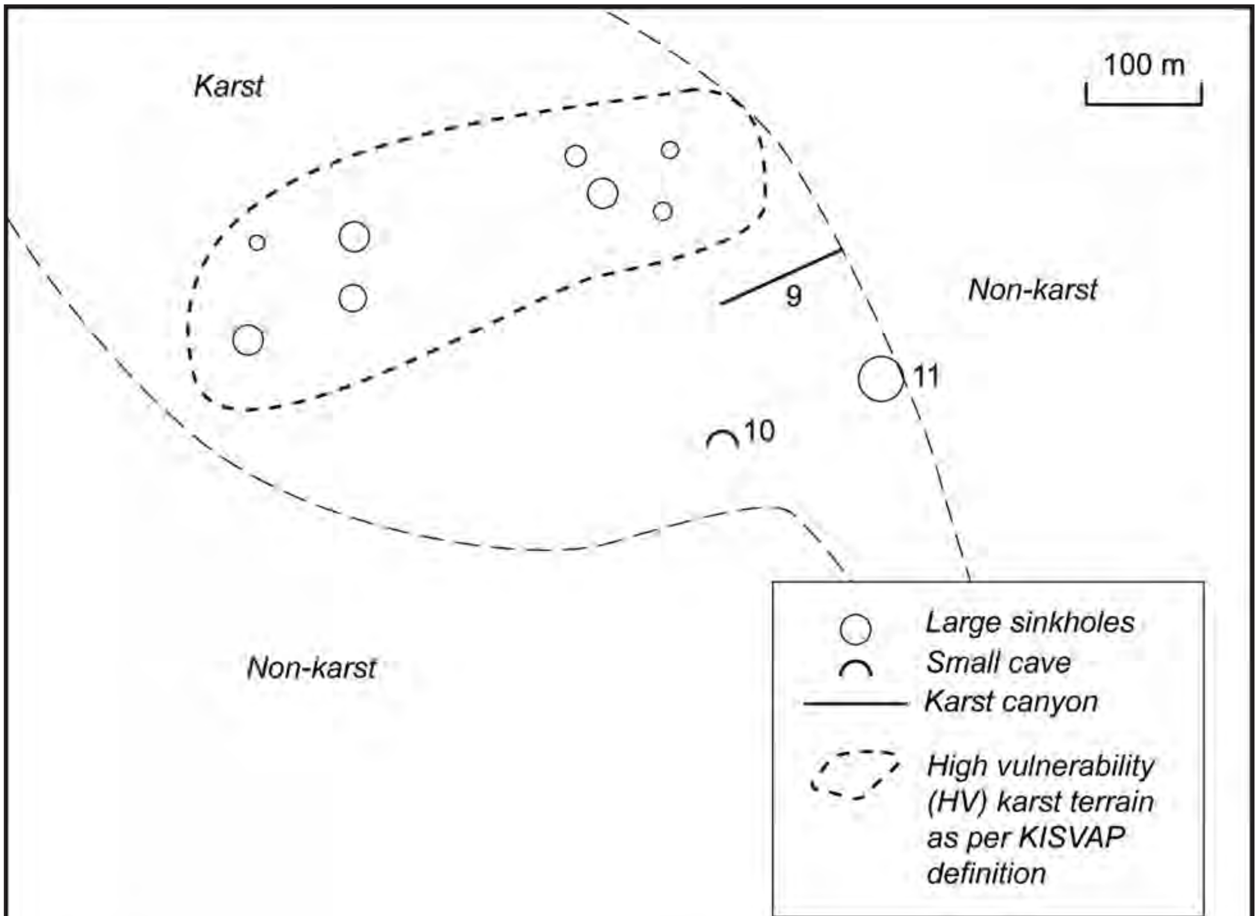
Another possible approach, provided there is no limit on how long a Government Actions Regulation order can be, would be to attempt to list and define all of the possible subcategories of karst resource features within the order itself. However, it is recognized that this could make for a very lengthy and cumbersome order with unintended legal restrictions (that is, there could be the risk of missing some of the important subcategories of karst resource features).

A third option would be to leave details on subcategory definitions to the realms of professional reliance and due diligence, which are cornerstones of the results-based the Forest and Range Practices Act.

2. <u>Defining "Damaged or Rendered Ineffective"</u>

As discussed earlier, Section 70(1) of the Forest Planning and Practices Regulation stipulates that an authorized person who carries out a primary forest activity must ensure that the activity "does not damage or render ineffective a resource feature."

At present, it is difficult to determine a government definition as to what "damaged or rendered ineffective" might mean for a specific karst



CRFD and QCIFD Draft Orders		SIFD Draft Order	
Feature 1	Covered	Feature 1	Not covered
Feature 2	Covered	Feature 2	Not covered
Feature 3	Covered	Feature 3	Not covered
Feature 4	Covered	Feature 4	Not covered
Feature 5	Covered	Feature 5	Not covered
Feature 6	Covered	Feature 6	Not covered
Feature 7	Covered	Feature 7	Not covered
Feature 8	Covered	Feature 8	Not covered
Feature 9	Covered	Feature 9	Not covered
Feature 10	Covered	Feature 10	Covered
Feature 11	Covered	Feature 11	Not covered
Plus the HV karst terrain is covered		... and no karst terrain is covered	

Figure 6: Example Map Showing Key Differences Between the South Island Forest District Draft Order and Campbell River Forest District and Queen Charlotte Islands Forest District Draft Orders for Karst.

resource feature. Ideally, there could be a threshold level above which a karst feature would be considered "damaged or rendered ineffective." Very simply, this threshold level could be judged to be exceeded for a feature when impacts resulting from the primary forest activity are found to be beyond the range expected when utilizing practices recommended in the Karst Management Handbook for British Columbia. The best management practices in the Karst Management Handbook are founded on the widely accepted principle that not all karst features are equally significant or susceptible to primary forest activity impacts. Accordingly, the recommended practices are varied and designed to meet a set of management objectives specific to each karst feature or karst terrain type. The Karst Management Handbook recognizes that a certain amount of disturbance is unavoidable whenever the soil-vegetation system components of a karst ecosystem are subjected to primary forest activities. The provincial karst management strategy as expressed in the Karst Management Handbook and other government karst guidance documents does not recommend full protection (that is, no harvesting) as an objective for every karst feature or karst terrain type.

Defining what is meant by "damaged or rendered ineffective" could eventually entail factoring in the degree of damage or ineffectiveness using indicators for karst such as those already developed and field tested under the Forest and Range Practices Act Resource Evaluation Program. Compliance and enforcement personnel would then be trained to use the karst indicators and monitoring protocols to recognize the results of inappropriate forest practices for karst resource features identified by the orders. Some concerns have been raised about possible contentious interpretations of the meaning of "damaged or rendered ineffective." However, it is felt that professional reliance and due diligence will assist in addressing these concerns.

In summary, the meaning of "damaged or rendered ineffective" could probably be determined based on the circumstances of each specific occurrence of alleged noncompliance. Ultimately, it may be decided by jurisprudence, in the same way that Courts in British Columbia have decided the meaning of "harmful alteration, damage or destruction" of fish or fish habitat.

3. Proposed Temporary Variance

An addendum could be added to the draft the Government Actions Regulation orders for karst that incorporates a Temporary Variance that would allow time for the development of an interpretation bulletin and other specific guidance for the Forest Planning and Practices Regulation Section 70(1) practice requirement. This would also allow time for instruction and training of government compliance and enforcement personnel. An example of a temporary variance is outlined as follows:

Draft of a Proposed Temporary Variance

The following practices are established as management requirements for the following subcategories of resources features identified by the karst order: surface karst features (including cave entrances not classified as significant enough to require full protection) and high vulnerability karst terrain.

1. Timber Harvesting – If, upon review, the quality of the karst feature or karst terrain will not be significantly affected in the opinion of a qualified karst professional.
2. Road Construction – In the case of high vulnerability karst terrain, if the road permits local access to timber or access beyond in non-karst areas or karst terrain of low or moderate vulnerability, and if, upon review, the quality of the high vulnerability karst terrain will not be significantly affected in the opinion of a qualified karst professional.
3. Road Maintenance and Deactivation, and Silviculture Treatments – If, upon review, the quality of the karst feature or karst terrain will not be significantly affected in the opinion of a qualified karst professional.

A "qualified karst professional" for the purpose of the proposed temporary variance would be defined based on the qualifications suggested in the *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia*.

FAQ Web Site on Karst Orders

The issues surrounding legally supported practice requirements for karst under the Forest and Range Practices Act are complex and can be difficult for members of industry, stakeholder groups, government, and the general public to sort out. In the interests of clarifying some of these issues, a FAQ Web site was developed by members of the professional karst community:

http://www.island.net/~subterra/FAQ.htm

This Web site is periodically updated as developments pertaining to the proposed the Government Actions Regulation orders for karst unfold. There have been over 5,000 hits on this Web site since its inception, which suggests that not only is there a need for clarification about the current state of karst management in British Columbia, but also that there is a high level of interest in the recent developments described in this paper.

Next Steps for Karst Management in British Columbia

The eventual passage of effective Government Actions Regulation orders for karst in British Columbia may prove to be highly significant because without such orders, and in the absence of any other the Forest and Range Practices Act provision that could be applicable to karst, there are presently no specific legal requirements to protect or manage karst resources under the new results-based forest practices regime.

The Forest Planning and Practices Regulation specifies a practice requirement to protect karst resources from the effects of primary forest activities by established legal orders, with significant penalties for noncompliance. However, as of this writing, the passage of the proposed the Government Actions Regulation orders for karst is in limbo, and it remains to be seen what form they will take or how effective they will be at protecting karst.

As with other resource values under the Forest and Range Practices Act, the responsibility for karst management in British Columbia is shifting from the government to licensees. The licensees are responsible for managing risk and ensuring sustainable forest practices are implemented. This responsibility would include determining whether karst field assessments are required prior to operating in a karst area. Licensees are also expected to ensure that staff or contractors consider recommended best management practices or otherwise provide a rationale for not doing so. This approach relies heavily on the participation of registered and/or qualified resource professionals who can be held accountable for their work, including geoscientists, biologists or foresters.

It is anticipated that the due diligence emphasis in the Forest and Range Practices Act will motivate the more consistent use of qualified karst professionals. There are but a few karst resource experts or specialists in British Columbia at the present time. Many resource professionals have no specific knowledge or experience related to karst. Despite the emphasis placed on professional reliance under the Forest and Range Practices Act, there continue to be cases where the assistance of qualified karst professionals is not sought. As well, resource professionals have occasionally rendered opinions for karst without adequate experience or knowledge.

Legally supported requirements for karst could actually enhance timber supply because the the

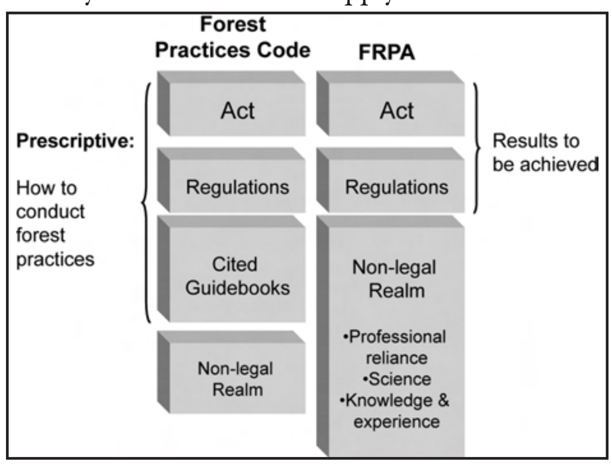


Figure 7: The Shifting Balance: From the Forest Practices Code to the Forest and Range Practices Act.

Government Actions Regulation orders under the Forest and Range Practices Act have the potential to facilitate more efficient harvesting operations in karst areas. Licensees who improve and expand their karst knowledge, or avail themselves of the appropriate professional advice, could conceivably gain better access to commercial timber in karst areas, while still achieving the desired management outcomes for karst.

The benefits of sustainably managed karst resources are without question important to shareholders and customers of forest companies worldwide, and of course to the public on whose behalf these resources are being managed. Raising the level of awareness of karst could lead to greater public benefits from these resources. Commercial and non-commercial recreation and tourism, and scientific research activities, for example, are bound to become more prevalent as more people discover the myriad non-timber values of coastal British Columbia karst forests.

Conclusions

The Forest and Range Practices Act, a results-based regulatory framework, replaces the more prescriptive Forest Practices Code, which has guided forest management in British Columbia since 1995. Freedom to manage has been actively sought by industry; however, it comes with added responsibilities.

Karst is a subset of resource features, one of the 11 key resource values specified in the Forest and Range Practices Act. The British Columbia government presently sets no objectives for managing karst under the Forest and Range Practices Act or its associated regulations; however, objectives for karst may be provided in land-use plans or Sustainable Resource Management Plans, or if karst resources are established as an interpretive forest site, recreation site or recreation trail with objectives.

Under the Government Actions Regulation, the surface and subsurface elements of a karst system can be legally established by order as resource features. This is the first time that karst has been recognized in legislation in British Columbia. Karst resources can be established as resource features by type or category, and may be restricted to a specified geographic location. Specific karst features and categories of easily recognized, well-developed broad karst landscapes might meet this requirement.

With the establishment of the Government Actions Regulation orders for karst, implementation of a karst management system would in effect no longer be discretionary, it would be compulsory and results-driven. The Government Actions Regulation orders are therefore regarded as the "missing link" in the transition to a results-based forest practices framework (Griffiths *et al*. 2005).

The proposed karst orders represent a significant milestone for karst management in coastal British Columbia's temperate forests, enabling legally supported practice requirements based on documents such as the *Karst Management Handbook for British Columbia*. Once established, the karst orders will be looked upon as an important first step on the way to achieving parity with current world leaders in the protection and management of karst resources in coastal temperate forests (for example, federal forest lands in southeast Alaska).

British Columbia currently has a comprehensive framework for karst management, including a karst inventory system, best management practices for forestry operations on karst terrain, and is in the finishing stages of developing monitoring protocols for evaluating karst management under the Forest and Range Practices Act. The development and implementation of a karst-specific monitoring program is likely to facilitate the periodic updating of recommended best management practices. This indicates an ongoing commitment by the British Columbia Government to manage its karst resources.

As one of the few jurisdictions in the world to move toward a results-based regulatory regime, it is anticipated that experiences in British Columbia will be of value to karst management specialists in other forested karst regions, particularly in the coastal temperate rainforests of Alaska, New Zealand, Australia (Tasmania), and Chile.

Acknowledgement of Reviewers

The authors would like to thank the following people for acting as technical reviewers for this paper: Brian Eccles, Hal Reveley, Jim Snetsinger, and Paul Tataryn, British Columbia Ministry of Forests and Range.

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CHINESE/AMERICAN COOPERATION IN CAVE MANAGEMENT AND STUDY AT WANHUA CAVE, HUNAN PROVINCE, CHINA

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Abatract

The Hoffman Environmental Research Institute of Western Kentucky University, and the Karst Geology Institute of China, have cooperated for more than ten years in studies in the karst regions of China. In 2004, the Wanhua Show Cave Company requested assistance from the Karst Geology Institute of China to address some of their cave management concerns. These included delineating the recharge area of Wanhua Cave, exploring new passages, determining the relationship of caves adjacent to Wanhua Cave, and outlining the significance of cave features within the show cave. In this effort to aid Wanhua Cave staff in the management of their cave, the Karst Geology Institute and Wanhua Cave Company provided transportation and logistical support and Hoffman Institute provided personnel to continue cave exploration and documentation, conduct dye tracing, geologic reconnaissance, and basin delineation. Two kilometers of the show cave were remapped and photo-documented. Two dye traces were conducted that established the relationship of Wanhua Cave to two other significant caves in the area. The dye traces and geologic and hydrologic reconnaissance helped establish the boundaries of the Wanhua Cave drainage basin. Hoffman Institute personnel worked with the Wanhua Show Cave staff to improve the content of their interpretive tours and to produce a new map. As a side benefit, Chinese media coverage of the project provided an opportunity for the people of Hunan to increase their awareness of various caves in their province.

CASTLEGUARD CAVE DIGITAL MAPPING – VOLUNTEERISM OVER FOUR DECADES

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Abstract

Though known since the 1920s, Canada's longest (20 km) and arguable most famous cave, Castleguard, was only extensively explored starting in 1967. These initial explorers were part of the McMaster University karst research group. Continuing on to the present, cavers from across Canada and around the world have participated in the exploration, study, and mapping of this international caliber resource located in Banff National Park. It is the only known cave under an icefield that has passages blocked by glacial ice extruding into it.

The production of a large scale map had often been talked about but never realized until recently. Parks Canada went to the public source best able to provide the expertise, the Alberta Speleological Society. Encouragement was given towards pulling together the vast amounts of survey data for the goal of the large-scale map.

By November 2004, Dan Green of the Alberta Speleological Society, was ready to release the first large scale and digital map of the cave. It consists of two versions; a set of six map sheets 1 by 2 meters and a set of 56 field sheets 8.5 by 11 inches in size.

In March 2005 Dan (ASS) and Greg Horne (Parks Canada) lead a volunteer group of five cavers (members of Alberta and British Columbia speleological societies) to start to use the base map for the purposes adding missing information, correcting errors, and inventoring of cave resources. Five days were spent underground camped about 5 kilometers into the cave. The trip expectations were well met. Future volunteer visits to continue the collection of information are possible.

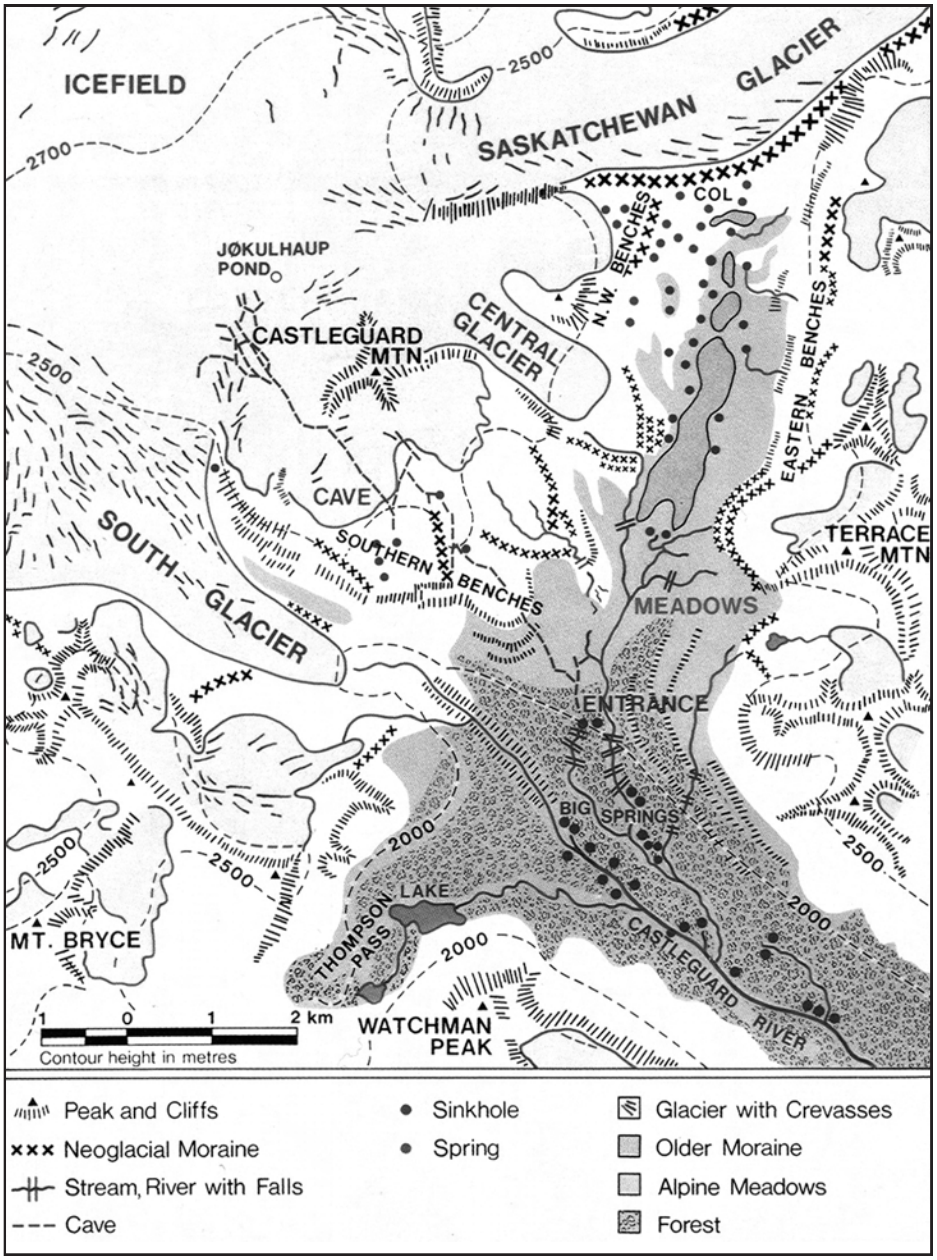
Although this type of cooperative cave exploration, survey, and map drafting project is common in other countries. It is the first time a project of this magnitude has occurred with Parks Canada.

Setting

Castleguard Cave is located in the northwest corner of Banff National Park, Alberta, Canada. The single entrance is situated just below the treeline. In summer, periodic resurging glacial flood waters issue from the cave. It is the only known cave under an icefield that has passages blocked by glacial ice extruding into it.

Background

Although discovered in 1921, an 8-meter vertical drop near the entrance barred further access until cavers from McMaster University karst research group descended the pitch and began the serious exploration of the cave. By the late 1980s the exploration and survey drive had nearly ceased. Twenty kilometers had been recorded. The very linear character of the passage layout and narrow nature



The Castlegard area.

of the cave passages did not encourage the need for a large scale map. A line plot represented the cave very well when presented at 11 by 17 inches.

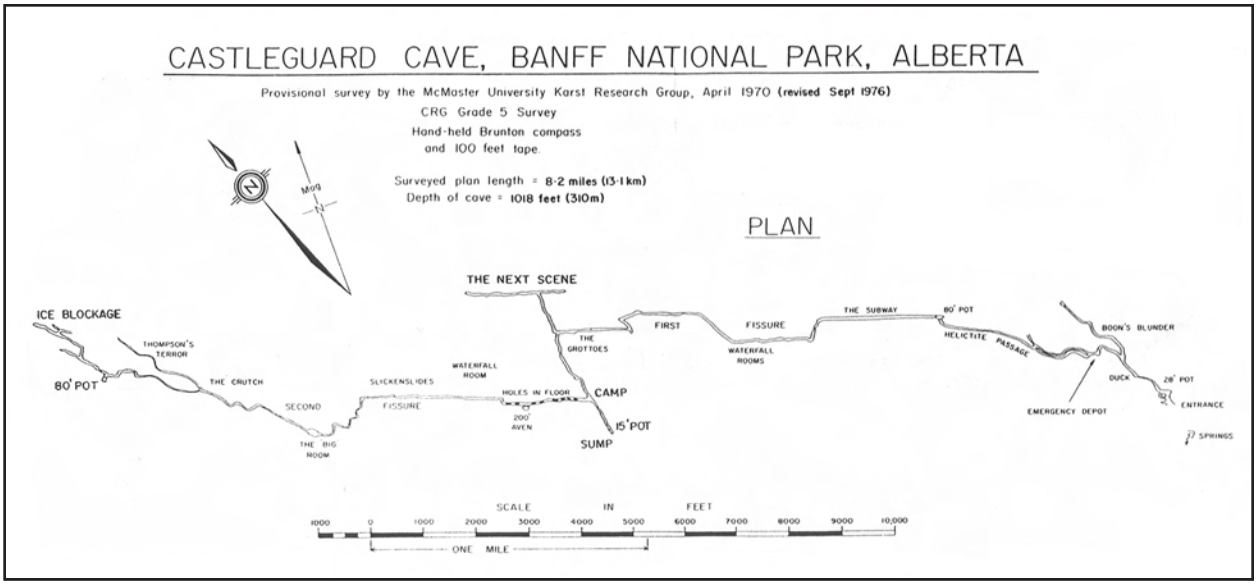
Though often talked about, a large scale map had never been drafted. The entrance to back-of-the-cave straight line distance is about 5.5 kilometers. A map at the scale of 1:1,000 would be 5.5 meters long. If produced, where and how could it be viewed? Advances in digital mapping that are possible from a home computer made the final map scale much less significant an issue.

The Project

The obvious need to assemble, refine, and present decades of survey data information collected in the cave was realized by Parks Canada. Part of that process would be the production of a large-scale map that would be the basic framework to which all other components could be related. With no base map, how could resource inventory, impact mapping, or exploration potential proceed?

Parks Canada went to the public source best able to provide the expertise, the Alberta Speleological Society. Given the past history of misunderstanding and mistrust, a slow relationship building process began. It involved sharing of information, participating in cave exploration, survey, and restoration activities together. As time passed I gave encouragement towards pulling together the vast amounts of survey data towards the goal of the large-scale map. Alberta Speleological Society member Taco van Ieperen, computer programmer by profession, took the plunge and began the daunting process.

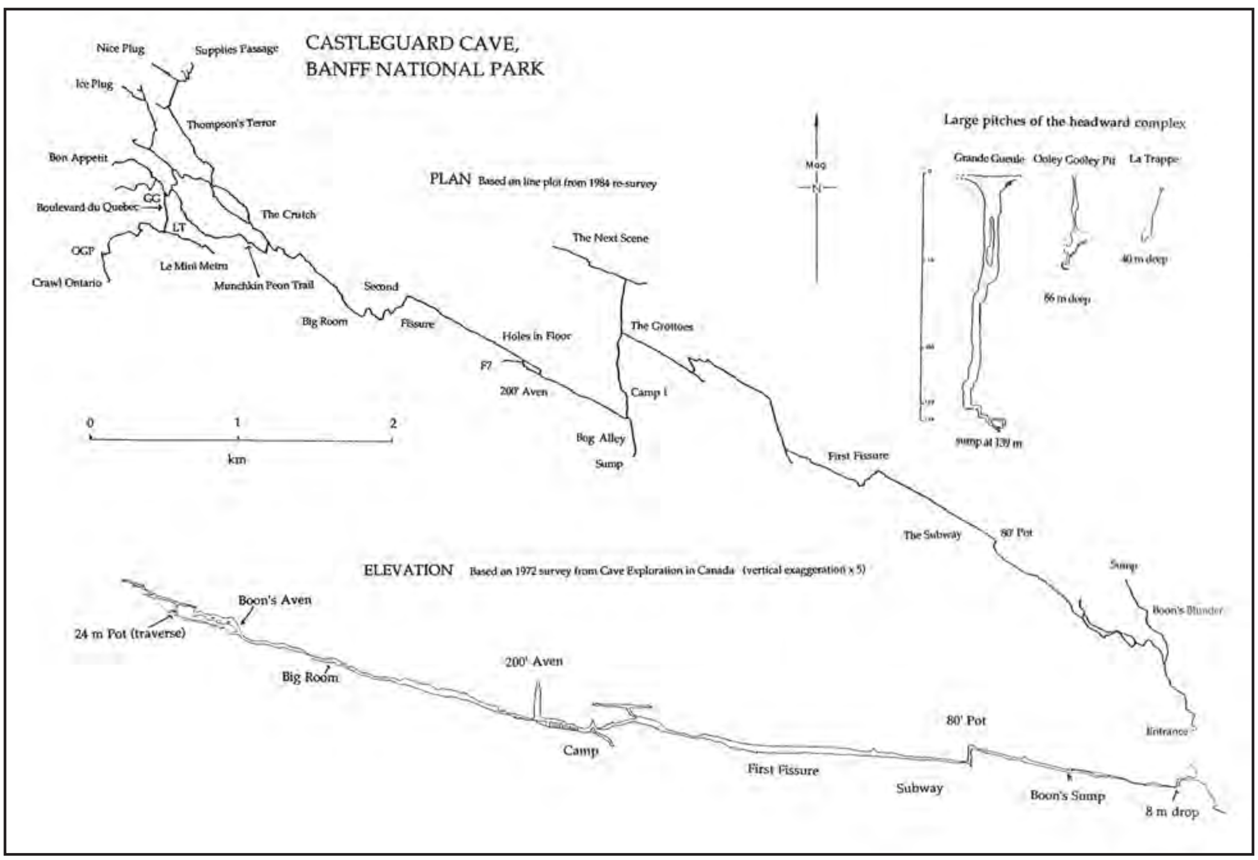
Another society member, Dan Green, learned of the map project. His past participation in major cave mapping projects in Mexico and being a design professional drew him to volunteer his time to transform Taco's very important computer data input and sketching efforts into a base digital map. He used the computer program Adobe Illustrator



The Castleguard Cave map in1976.

in conjunction with the cave survey program Walls. This process was more than two years of work in the evenings and days off. There were major computer heartburn hiccups along the way. Continued dialogue, suggestions, and moral support by me kept Dan progressing forward.

Then, in November 2004, Dan was ready to release the first large-scale map and digital map of the cave. It consists of two versions; a set of six-map sheets 1 by 2 meters and a set of 56 field sheets 8.5



The 1984 line plot of Castleguard Cave.

by 11 inches in size. The field sheets would be the format to be taken into the cave.

In March 2005, Dan and I lead a volunteer group of five cavers (members of Alberta and British Columbia speleological societies) to start to use the base map for the purposes adding missing information, correcting errors, and inventorying cave resources. We spent five days underground camped about 5 kilometers into the cave. Our trip expectations were well met. Numerous future volunteer visits to continue this process are possible.

This volunteer project highlights the possibility of forming a partnership between a special interest user group and Parks Canada for the purposes natural resource discovery, inventory and therefore better resource management. The special interest and skills required for many aspects of this project plus its scope necessitated participation of the public. In total more than 50 people have donated thousands of volunteer hours from 1967 to present to bring the map to its current state. Continued communication and interaction between user and land manager are required to maintain this mutually beneficial relationship.

The continuation of this article is by Dan Green.
Dan's perseverance and determination resulted in a map product that will serve this generation's and next's Castleguard users.

The Castleguard Map

Digital Mapping using Walls and Adobe Illustrator 10

In the late 1990s Taco van Ieperen of Calgary compiled 30 years of survey data, sketches, and partial maps for Alberta's Castleguard Cave and generated a monumental pencil sketch on 60 letter-sized sheets of paper. His groundwork inspired the final digital inking. A digitally finished map makes sense for such a large cave because it allows a combination of artwork, survey data, and other information to exist in different layers within one master file. Digital maps are easy and cheap to store on hard drives or CDs, and they allow simplified distribution and updating.

The basic steps for making cave maps remained unchanged since the early years but recent software has improved data management and common vector drawing programs are ideal for digitally inking a cave map. With traditional survey notes, the basic steps for producing a cave map start with organizing the data and getting a line plot, then drawing a pencil sketch over the line plot and finally "inking" a finished drawing. I initially saw my role as completing the finished drawing but getting there involved a total reorganization of the survey data that in turn meant restructuring the artwork to match.

Vancouver caver friend and GIS administrator Tyson Haverkort supported my concept idea of creating this master file and helped me launch the project with Parks Canada through Jasper Park caving warden Greg Horne in 2001. The major steps for getting the project from pencil sketch to a series of both large wall maps and smaller field maps included:

- Converting the pencil sketch to images manageable on the screen.
- Reworking the data from OnStation into WALLs to get the line plot.
- Arranging the digitized sketches over the line plot.
- Building a library of symbols and lines and inking the artwork.
- Rebuild the WALLS data with newfound data and invoking magnetic declination for true line plot.
- Restructuring the artwork to match the updated line plot and completing the master file
- Producing wall maps and field maps from the master file

Pencil Sketch: From Paper to Screen

The pencil sketch was drawn on letter-sized sheets, taped together in blocks, and these had to be digitized into manageable screen-friendly images. We taped the 57 pencil sketch sheets together on top a large piece of pattern paper a meter wide by eight meters long. Tyson managed to have this scanned on a wide-format scanner. Amazingly he e-mailed this to me as a mysteriously compressed TIFF that was only 1.3 mbytes. But it was only readable in AutoCAD, a program I didn't understand at all. I wanted to work in a familiar vector drawing program. Trying to open the file would crash most computers, so for a while the project took a back seat to others. In March 2003 Vancouver Island caver Craig Wagnell and Indiana caver Aaron Addison proved the file workable. Craig managed to open the scan and reduce it to manageable bits. His computer had taken a while to open the file, but had managed to unzip the 1.3 mbyte scan to 2,000 mbytes. He sent me 75 small files in different formats (PDF, JPEG, TIFF, PSD, AI), exactly what I needed to begin puzzling it back together on the screen. This would lay the foundation for digital "tracing."

Line Plot: OnStation to WALLS

A true line plot was needed as the first layer for the digital inking in Illustrator. This is the foundation that the sketches and entire map would be arranged over. The pencil sketch was made over a line plot but was fragmented on many taped together sheets sure to have misalignment error. The Castleguard survey data was in a very rough OnStation file converted from SMAPS. Most of the data was grouped together in logical regions of the cave, but nothing was labeled and there were no keys; much time was spent figuring out which survey legs were which, and where they were. A large chunk of the data was in feet and tenths of feet that I converted to meters with Excel. I began rearranging the survey data in WALLS survey management software. WALLS is regularly updated software by David McKenzie in Austin and includes features like the International Geomagnetic Reference Field (IGRF, a mathematical model of Earth's magnetic field and annual rate of change) and Scaleable Vector Graphic (SVG) options that integrate the data and artwork with Adobe Illustrator to integrate and reflect updated survey changes and additions. Eventually the data was regrouped into general areas of the cave, nothing too specific, and redundant data deleted, but unknown data was missing that I decided to track down later. I exported the line plot with stations names and a grid from WALLS as a Windows metafile and imported this into Illustrator to begin placing the JPEG sketch files above it. Big mistake. I should have spent more time tracking down the missing data and making sure it was perfect and up to date. This would delay the project for more than half a year.

Pre-Inking: Arranging Digitized Sketches Over the Line Plot

By this time I'd replaced the PC and AutoCAD with a G4 iMac and Adobe Illustrator 10. I chose to use the 20 sub-1 mbyte JPEG files that puzzled together to make the entire cave, and lay them over the digital line plot to ensure both matched. Not surprisingly the line plot and artwork didn't precisely match up, but I'd been expecting to cut and paste the artwork to match so basically just arranged the sketches as best I could in their own layer. Illustrator allows any object to be made transparent, this allowed the line plot to easily show through and the sketches could be overlapped without blocking one another. Since we were shooting for a 1:1,000 scale, this meant the map would be over 6 meters long. Illustrator's artboard maxes out at 5.8 meters, so I instead worked the map in three different files. This was also useful for keeping the file sizes smaller as I would need to keep the larger-sized JPEGs I was tracing over as a layer until I was sure they could be removed.

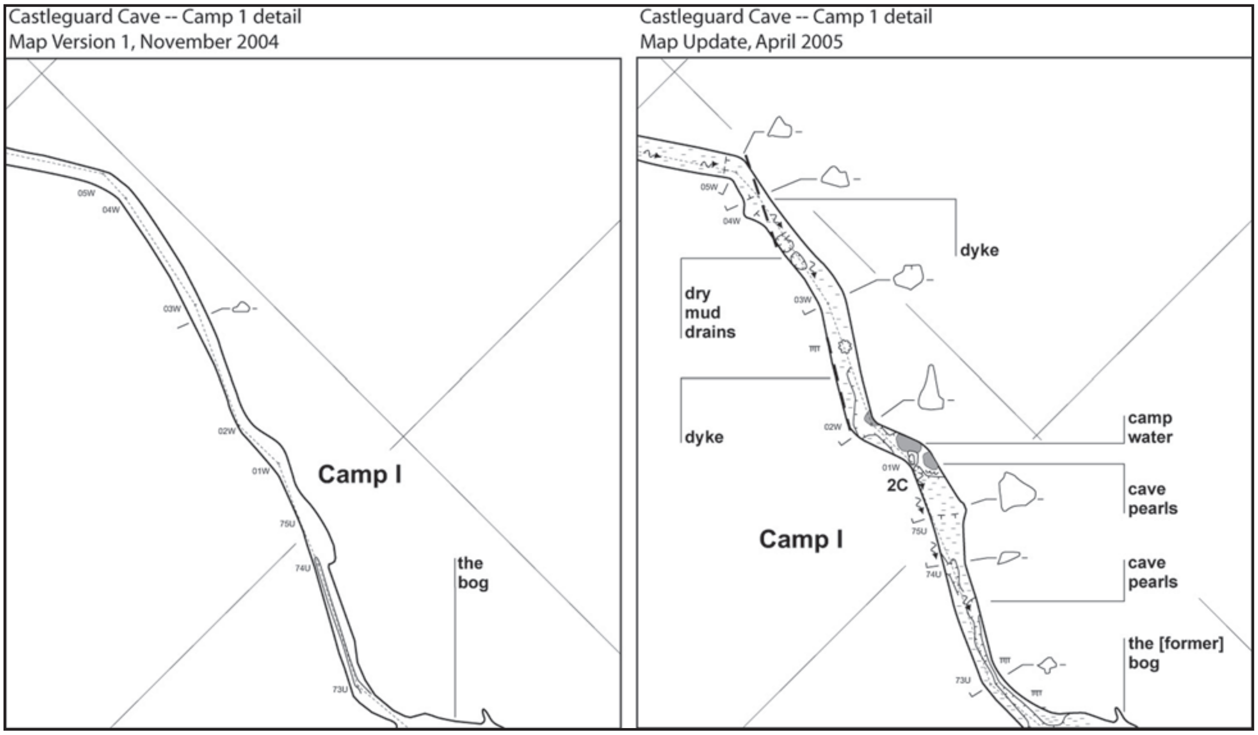
Library of Symbols and Detailing: Elements of the Artwork

I developed a library of symbols and line weights and rules to work with. specific line weights suited the walls and others suited floor detail. A specific format was designed for the many cross sections. I developed many rocks of different sizes and shapes, as well as stylized symbols for bedrock, mud, stones, and the like. Instead of diagonal lines and crosses I used fills along the grayscale for water and a customized fill indicating seasonal ice. With a complete library of standardized detail objects it's easy to copy them into the drawing later on.

Vector drawing programs like Illustrator let you create layers to organize different elements of the map. Each of these layers can be locked to prevent accidental selection, and each layer can be made visible or hidden with a click of the mouse. For example, I imported the line plot (complete with grid, survey stations and survey station markers) into one layer I called LINE PLOT and locked it. In another layer called SKETCHES I assembled all the scanned JPEGs to overlay the line plot, and then made them slightly transparent to allow the line plot to show through, then locked it also. I created a layer for the WALLS and began to "trace" the walls of Taco's sketch. Rather than trying to maintain a steady hand, Illustrator offers a pen tool where a click on the screen activates a line and another click anywhere draws the line between. The line can be curved and smoothed as you go or be adjusted anytime later with infinite control points. This method was essentially the same for drawing all the floor detail and cross sections. Dan Pach suggested using a combination of leader lines, simple font and multiple heading levels for the large amounts of type on the map. I completed the first draft of the master file by November 2003 and sent a copy to the Alberta Speleological Society AGM in Edmonton for review. Greg Horne coordinated the review as it was edited by Castleguard veterans Julian Coward in Edmonton, Ian Drummond and Ian McKenzie in Calgary, and then finally Chas Yonge in Canmore.

Rebuild Data: Magnetically Adjusted Line Plot

In the meantime I began rebuilding the survey file properly in WALLS, reorganizing files, first by year and then cave region and survey date. There were about 500 meters of slowly-emerging survey data missing or disconnected by sequence. I also invoked the magnetic declination calculator within WALLS that would adjust each individual survey



Camp 1 detail in version 1 as of November 2004 and after the April 2005 map update.

relative to true north, rather than to magnetic north that misaligns them relative to one another. Magnetic north has deviated roughly 4 degrees from when Julian Coward and Peter Thompson surveyed the Ice Plug in 1970 to the most recent 2005 Parallel Universe survey beneath Holes-in-the-Floor; without adjusting for magnetic deviation the line plots are thrown wildly off. By fixing the entrance station on earth with lat/long/elevation and assigning a date directive to each individual survey, WALLS produced the first accurate line plot of the cave. But this instantly threw the already completed artwork off significantly from the line plot upon which it was already built.

Final Edit: Update and Rebuild Master File

Working 100 meters at a time, I split apart the artwork and spliced it back together over the improved line plot. The final master map has many layers, any of which can be "turned off" to be invisible or locked to prevent changes. For example, it's easy to see and print the maps without any survey data by turning off the layers called Line Plot, Station names, and Station markers. Additional layers could be added at any time (colored water and words, a fauna layer, a topographical layer, a photo layer, and so on). Steve Worthington, who knows the cave well, became involved in the summer of 2004 and did the final edit on the map. He reviewed the survey data (many of the number/letter sequences he had assigned years ago) and came up with the remaining missing data.

Map Series: Generating Field Maps and Wall Maps

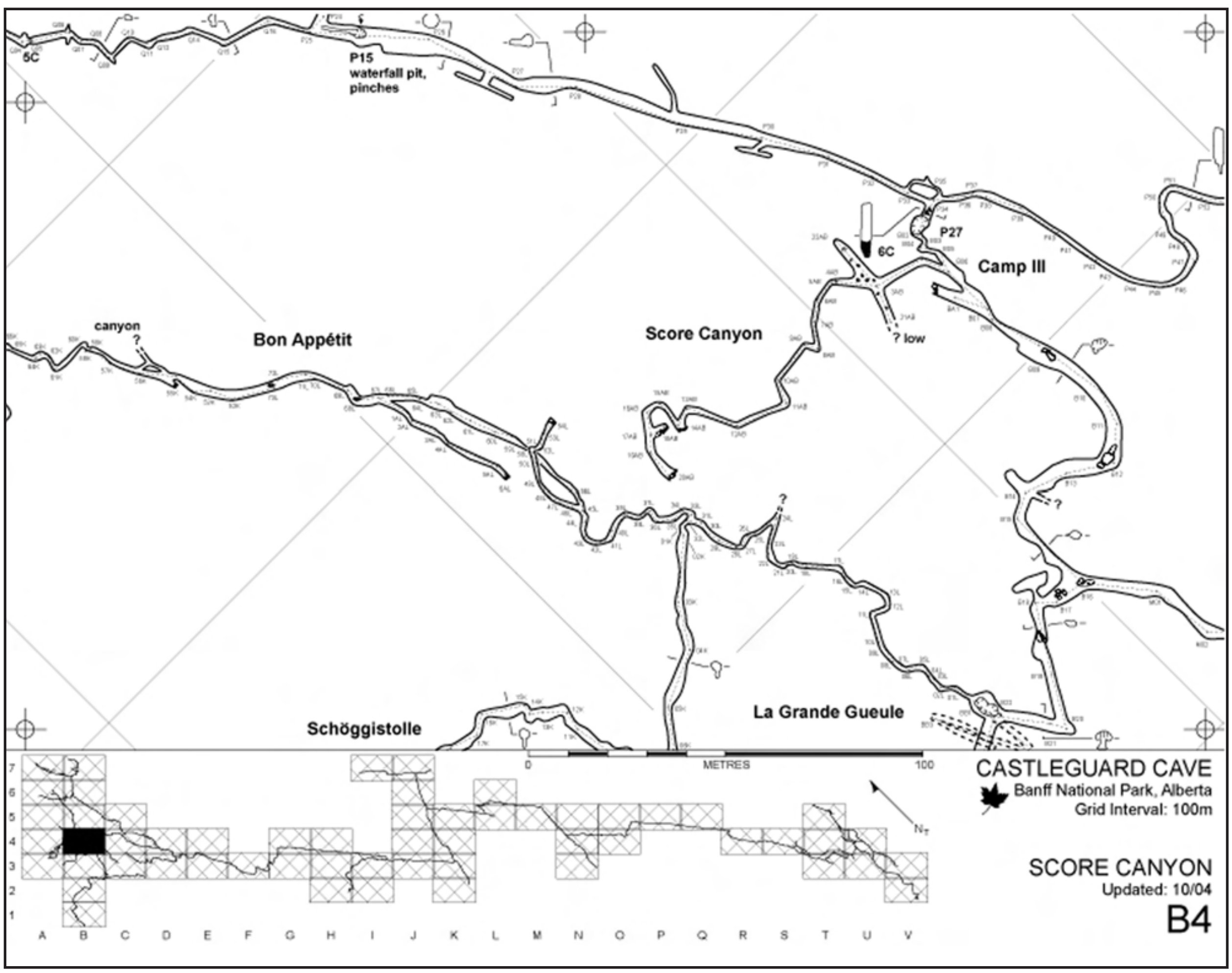
With the master complete I extracted both a Field map series and a Wall map series. The Field map comprises 56 letter-sized sheets and there are six tiled Wall maps. To maintain the layers format the master file was duplicated 56 times and everything but the artwork for each specific sheet was deleted. The remaining artwork was fitted into a frame and legend template and saved as its own map. The files were exported as relatively small PDFs and can be e-mailed or stored easily on hard drives or CDs (for example, the Field maps are only 6 mbytes and the Wall maps are about 500 kbytes each).

The field maps were used in Castleguard in 2005. A team spent four days at Camp 1 mapping missing passage detail in Next Scene, F7, and the

Grottoes, as well as studying isopods and checking unmapped leads. The maps worked well with the additional of the raw survey data cut and pasted onto each sheet — a new layer to be included on the next update. All updates to the map are done on the master, and affected map sheets are generated from that.

In recent years newer software emerged to allow cave maps to exist as dynamic projects created, updated, and viewed digitally, where hard copies would be only current snapshots. Using WALLS and Illustrator, Scaleable Vector Graphic (SVG) round-tripping makes it possible to link both the survey data and artwork together so that changes to the data (resurvey, new loops, and so on) are reflected accurately in the morphed artwork. This literally marries the survey data to the map. Some current cave projects have been using digital alternatives to the traditional process for map making. Instead of considering surveying and sketching the independent precursor for map artwork, some projects are recording the in-cave survey and sketch digitally which produces a scaled digital rough draft right in the cave. Some of these developments may be the next logical step for managing Castleguard as an ongoing project. There are many areas of the cave that lack adequate map information, good prospects for future trips. There remain over 40 unmapped leads.

Much thanks to Greg Horne and Parks Canada, The Alberta Speleological Society, Tyson Haverkort, Craig Wagnell, Aaron Addison, Dan Pach, Julian Coward, Ian Drummond, Ian McKenzie, Chas Yonge, Steve Worthington, and Taco van Ieperen.



KARST CONSERVATION IN THE OZARKS: FORTY YEARS AT TUMBLING CREEK CAVE

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Abstract

In this paper we detail nearly 40 years of scientific work and land management in and around Tumbling Creek Cave, Missouri. Tumbling Creek Cave is a famous educational and research cave on a rural property called the "Ozark Underground Laboratory." Tumbling Creek Cave has the highest cave biodiversity west of the Mississippi River, with about 112 species, including 12 troglobites and three endangered species: gray bats, Indiana bats and Tumbling Creek cavesnail. The cavesnail began declining in the 1990s, which prompted more intensive work towards land restoration and recovery of cavesnails and gray bats. The gray bat population has increased again, but the cavesnail will require more time and effort to recover. Land and cave remediation work have taught us many lessons that should be useful to others who manage large caves with rich resources.

Introduction

Tumbling Creek Cave, in Taney County, Missouri, has many interesting and valuable resources (Figure 1). A 1,032-hectare (2,550-acre) tract in southern Missouri karst serves as the home of the Ozark Underground Laboratory, established in 1966 and operated by Tom and Cathy Aley and their staff of six. Ozark Underground Laboratory conducts water tracing studies and consults on cave and karst problems in many locations. The cave's catchment area is 2,349 hectares (5,804 acres). The nonprofit Tumbling Creek Cave Foundation now owns 106 hectares (263 acres) around the natural entrance, to continue protection of the cave into the future.

Tumbling Creek Cave (Figure 1) is a famous educational and research cave and a National Natural Landmark (Aley and Thomson 1971, Elliott *et al*. 2005) Tumbling Creek Cave has the highest recorded biodiversity of any American cave west of the Mississippi River, rivaled only by Tooth Cave and Stovepipe Cave in Austin, Texas. Currently 112 species are listed in the Missouri Cave Life Database from Tumbling Creek Cave, including 12 species of troglobites (Table 1, Figure 2,4). Tumbling Creek Cave has appeared in a National Geographic special, other TV programs, news and scientific articles. The cave harbors three endangered species: gray bats (*Myotis grisescens*), Indiana bats (*M. sodalis*) and the Tumbling Creek cavesnail (*Antrobia culveri*, Figure 4). The latter is nearly extinct. Scientists have studied this cave in cooperation with the Aleys for nearly 40 years. The Aleys lead low-impact educational tours of the epikarst and the attractive cave for college and professional groups. Tumbling Creek Cave is protected and only light agriculture is practiced on the land.

High Biodiversity

Tumbling Creek Cave's biodiversity is mea-

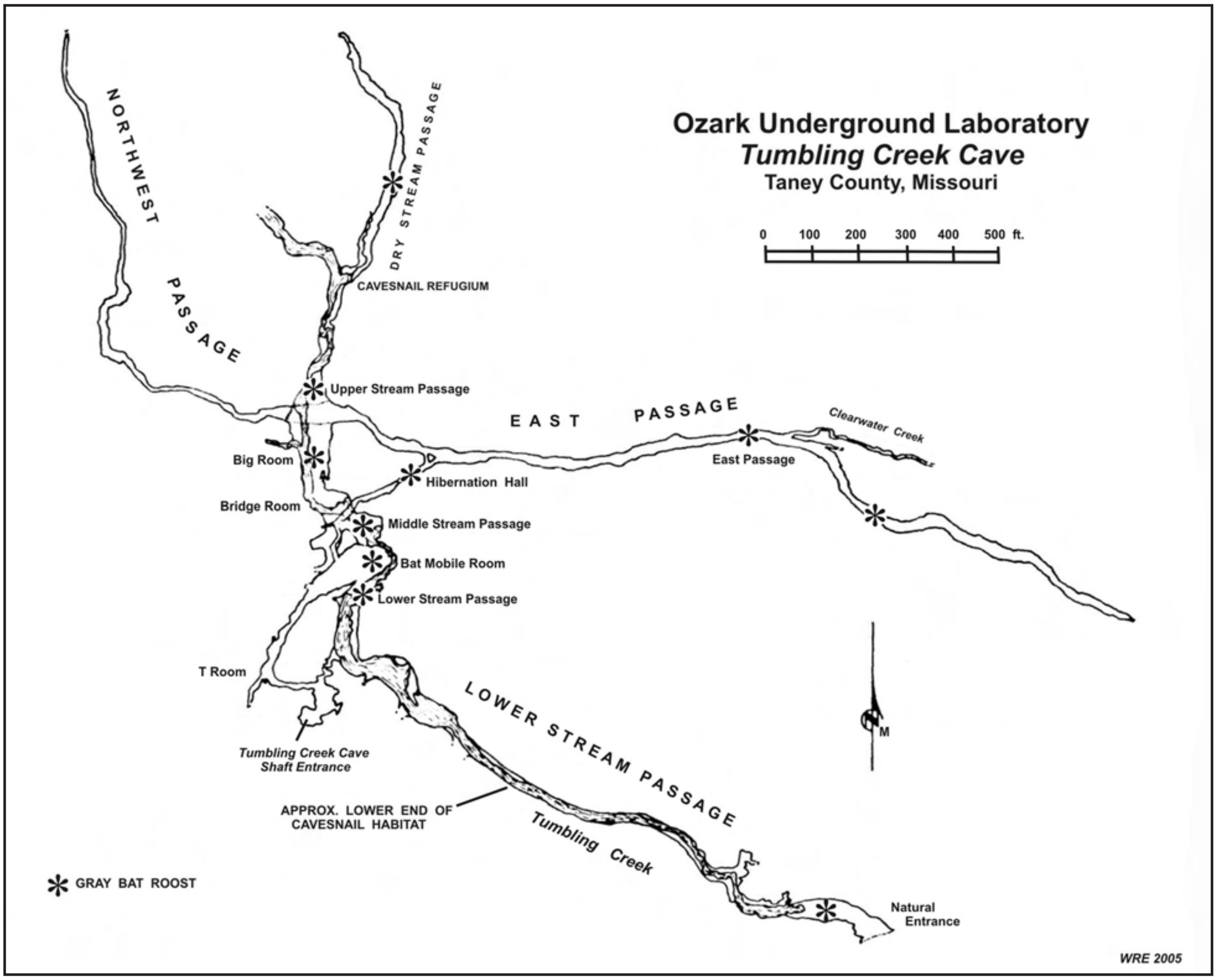

Figure 1. Map of Tumbling Creek Cave showing the extent of the cavesnail's range and major gray bat roosts.

sured not only in terms of its species richness, but in the rarity of its troglobites. Elliott has developed a biodiversity index for Missouri caves that accounts for the number of species, number of troglobites, and how endemic or rare those troglobites are (Elliott and Ashley 2005, Elliott 2006b). Some are unique to Tumbling Creek Cave, such as the cavesnail, a new millipede named after the Aleys, and a new isopod named after Dr David C. Ashley, biology professor at Missouri Western State University (Table 1).

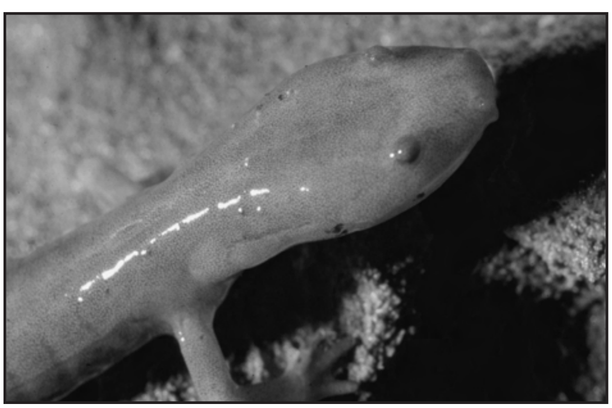

Figure 2. The Grotto salamander, commonly seen in Tumbling Creek Cave, is the trademark troglobite of the Ozark Region. Formerly known as Typhlotriton spelaeus, *the species is now* Eurycea spelaea *(see Bonnett and Chippindale 2004).*

Antrobia culveri	Tumbling Creek cavesnail
Arrhopalites clarus	cave springtail
Brackenridgia ashleyi	trichoniscid isopod
Caecidotea antricola	Antricola cave isopod
Causeyella dendropus	Causeyella cave millipede
Chaetaspis aleyorum	Aleys' cave millipede
Eurycea spelaea	Grotto salamander
*Islandiana sp.**	cave spider
*Phalangodes flavescens**	harvestman

Spelobia tenebrarum	Cave dung fly
Stygobromus onondagaensis	Onondaga cave amphipod
Stygobromus ozarkensis	Ozark cave amphipod

*Table 1. About 10% of Tumbling Creek Cave's species are troglobites Species in bold are unique to this cave, while two marked with an * may be troglophiles, which are less cave-adapted.*

Besides its biological resources, Tumbling Creek Cave is an attractive cave with a perennial stream, called "Tumbling Creek" for its polished chert pebbles similar to ones produced in a rock polishing tumbler. The Aleys lead occasional educational tours for college and professional groups. Each group gets an introduction to karst on the surface, views sinkholes, then enters the artificial shaft entrance, which has two airlock doors to keep the cave from drying out. The visitors bring their own lights and follow a rudimentary trail. The cave has been disturbed very little by this educational use.

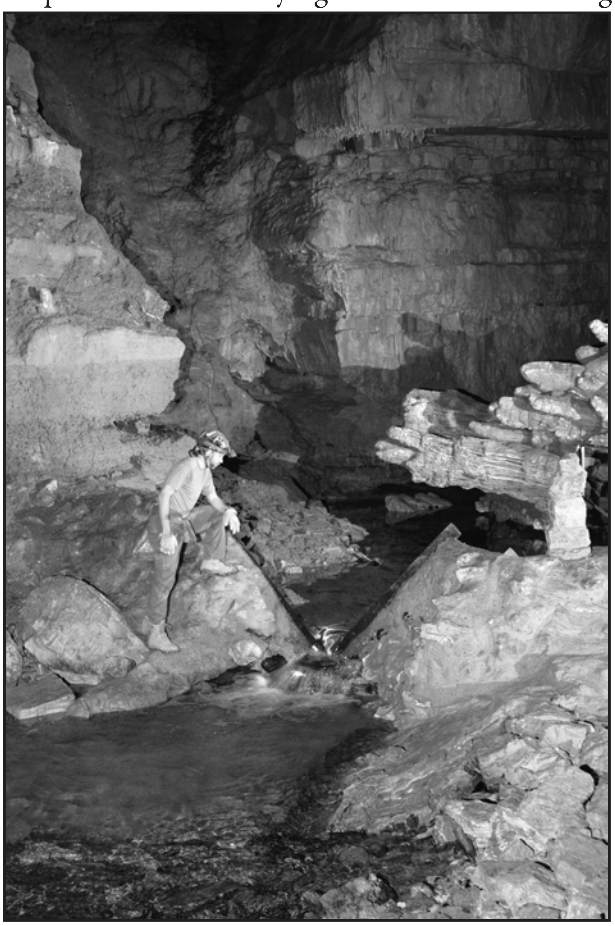

Figure 3. Steve Samoray at the weir in the Big Room, Tumbling Creek Cave, Missouri. This structure is used to visually gauge stream flow. Sensors in the pool beyond the weir register water quality paramaters to a data logger.

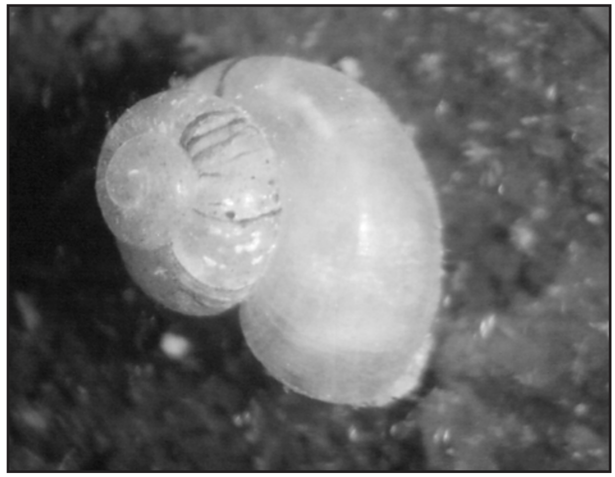

Figure 4. The Tumbling Creek cavesnail, Antrobia culveri *(by David C. Ashley)*

Review of Studies

Ozark Underground Laboratory has sponsored many studies of the cave and its life. The Aleys did extensive dye tracing to delineate the recharge area of the cave, and they studied groundwater infiltration rates to the cave. A state-of-the-art data logging system, designed by Ralph Ewers and Peter Idstein, is collecting water quality data from the cave stream. The Aleys also studied the potential long-term impacts of using bleach to control plant growth in show caves and natural alpha radiation concentrations on behalf of the National Caves Association. Other projects have included extensive studies of Tumbling Creek Cave's cavesnail and stream fauna by David Ashley (2003). Several biologists have estimated bat numbers since 1964, but the most detailed work has been since 2004 (Elliott *et al.* 2006c).

Four graduate theses were based on studies at Tumbling Creek Cave. Fair (1974) wrote a PhD dissertation on variations in water quality and quantity in stalactite drippage. Martin (1980) wrote a master's thesis on the arthropods of guano piles, greatly increasing the size of the fauna list. Fletcher (1982) wrote a thesis on the microbial succession on guano piles. Neill (2003) prepared a thesis on the effects of land use on Tumbling Creek Cave.

Figure 5. This neighboring farm was cleared and converted to little more than a cattle feedlot.

Recovery of the Cavesnail

Even though Tumbling Creek Cave is appreciated and protected well, something unexpected happened in recent years. In the 1990s a cattle operation was developed on a nearby farm (Figure 5), resulting in overgrazing and forest clearing, which loaded the groundwater with sediments. The cave has no open swallowhole upstream, but the sediments worked down through losing streams into the cave. Muck visibly built up in the cave stream, which is normally floored with cobbles. Some areas are so mucky now that one cannot pull up rocks that used to be loose. Now the tiny cavesnail, *Antrobia culveri* (Figure 4), is nearly extinct. In 1973, 15,118 cavesnails were estimated to live in the stream (Greenlee 1974), but a decline became noticeable by 1991. Population estimates of the cavesnails by Dr Ashley and Dr Paul McKenzie, United States Fish and Wildlife Service, have documented the decline since 1996 (Ashley 2003, Department of the Interior 2001, 2003, Figures 6 and 7).

The Tumbling Creek Cavesnail Working Group was founded by Paul McKenzie to bring together experts from the region (Department of the Interior 2001, 2003). We are studying the cave with other scientists to determine what happened. Sediments probably hurt the cavesnail and other life, but we also are checking for chemical contaminants with Semi-permeable Membrane Devices and Polar Organic Chemical Interactive Samplers that mimic live organisms in absorbing waterborne chemicals. Dr John Besser of the U.S. Geological Survey is analyzing sediment samples for heavy metals and organic contaminants.

Dr Paul Johnson, formerly of the Tennessee Aquarium Research Institute and now of the Alabama Aquatic Biodiversity Center, is an expert in propagating aquatic snails. Johnson is culturing two surrogate species of hydrobiid snails in his laboratory. If the methods are successful, and if enough *Antrobia culveri* can be

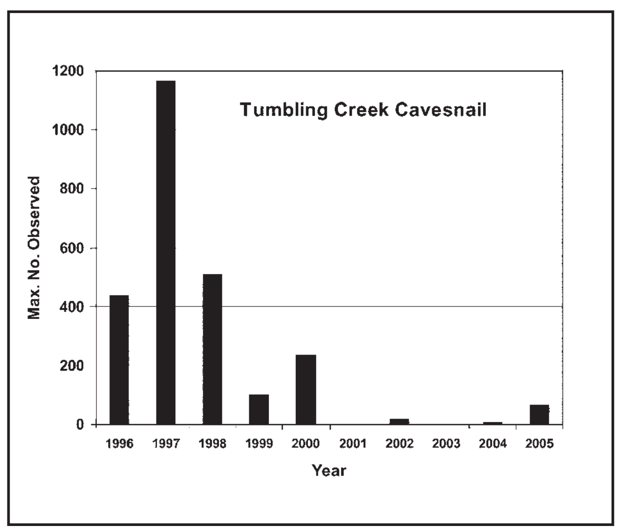

Figure 6. Bar graph showing the maximum number of Tumbling Creek cavesnails observed or estimated since estimates were begun in 1996 by Ashley and McKenzie. Greenlee had estimated 15,118 cavesnails in 1973.

Figure 7. Cavesnail census using a random quadrat method, August 31, 2001. Left to right are David Ashley, Paul McKenzie, and Andy Roberts.

found again, it may be possible to propagate them in a laboratory in Tumbling Creek Cave, and then put them back into a repaired Tumbling Creek. Funding has been provided by the U.S. Fish and Wildlife Service to set up a small culture system in the cave and construct a culture rack in a laboratory in Alabama. Ceramic tiles will be placed in Tumbling Creek to provide substitute reproductive habitat for *Antrobia culveri*. Dr Johnson will develop a basic culture and in-stream propagation plan for the cavesnails (Paul Johnson and Paul McKenzie, pers comm).

Land Management and Restoration

Light agriculture can be compatible with a karst system, and the Aleys do some cattle raising and hay cropping on parts of their land. The Missouri Department of Conservation and the U.S. Fish and Wildlife Service are assisting the Aleys, who bought the nearby abused property with their own funds. With cost-share funds they replanted 70,000 trees to restore the land. They have overseen the planting of native species, such as black oak, northern red oak, white oak, black gum, black walnut, green ash, dogwood, redbud, sycamore, and a few short-leaf pines (Figure. 8). They expect that sassafras, hickories, and persimmons will re-establish naturally from the surrounding areas.

Another cost-share project with the National Park Service is helping to identify and characterize old dumps in the recharge area for the cave. A total of 23 dumps have been discovered to date, and work is underway to remove the trash. To date about 65 tons of scrap steel have been shipped to a recycling facility and another 40 tons awaits shipment, but the work is not yet finished. These efforts

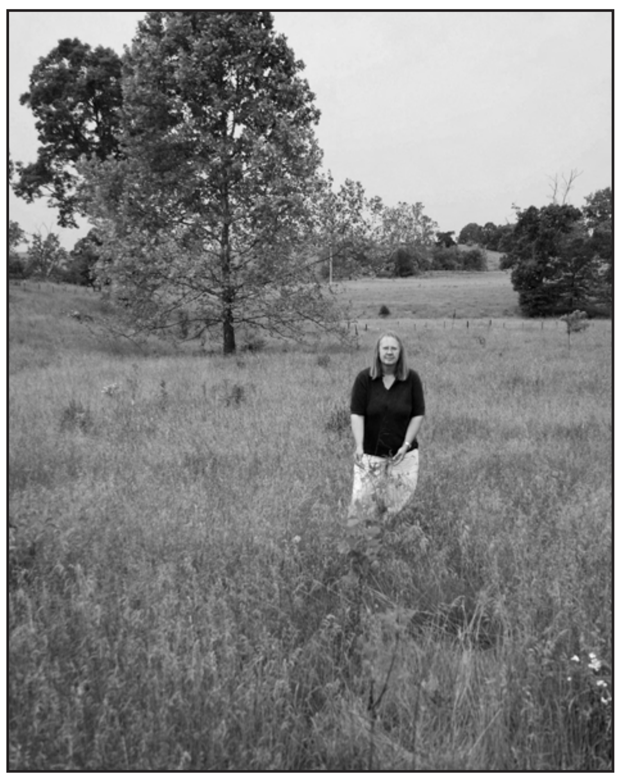

Figure 8. Cathy Aley shows one of 70,000 young trees planted in an effort to restore the abused land near the Ozark Underground Laboratory.

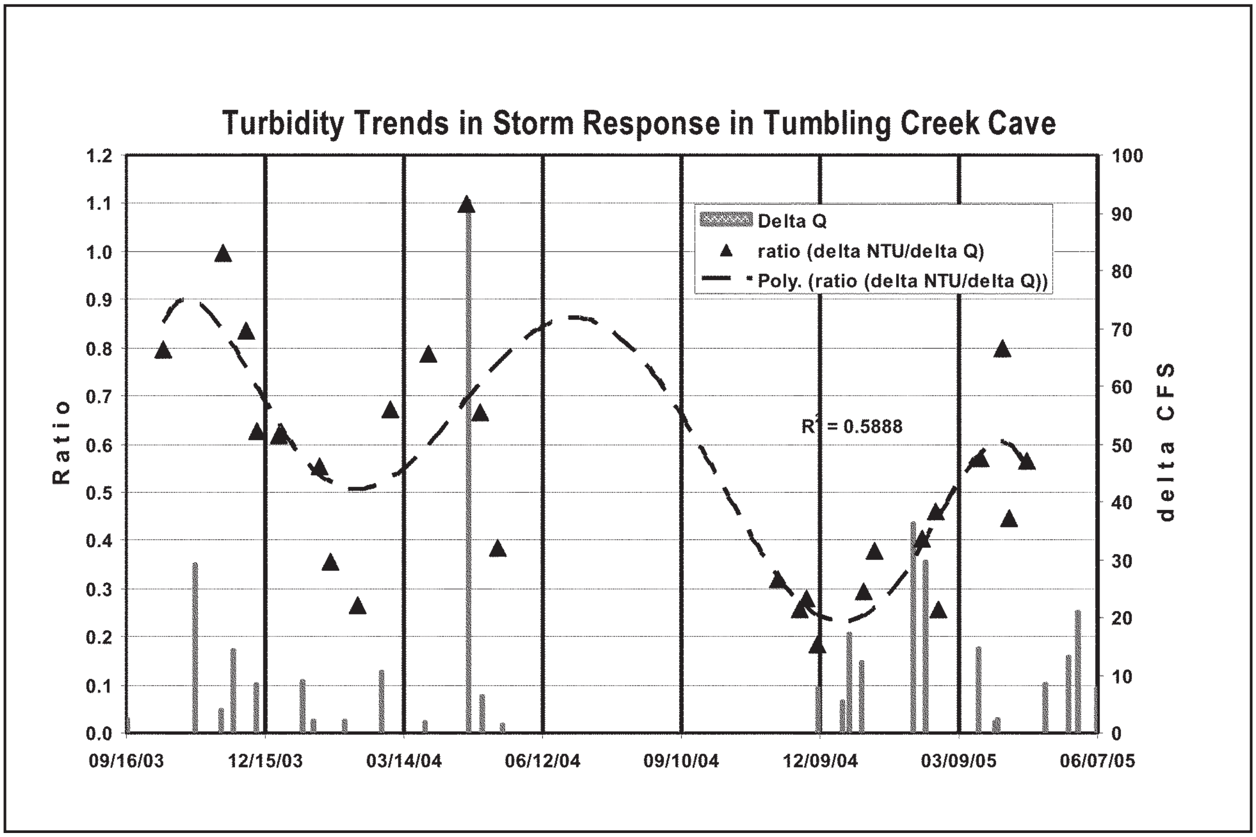

Figure 9. Turbidity trends in storm response in Tumbling Creek, using the delta values for both turbidity and discharge, as measured with in-stream sensors and a data logger. There are two apparent trends: more intense storms and turbidity in the summer and a trend towards lower ratios of turbidity to discharge from 2003 to 2004. These trends are based on few data points and more work is needed.

may already be paying off. Figure 9 depicts a possible decline in turbidity in Tumbling Creek, as measured with in-stream sensors and a data logger.

In 2005 major improvements to the Ozark Underground Laboratory sewage systems were constructed. The new system collects all sewage effluent generated on-site and transports it through a combination of pressure and gravity systems to a large disposal field located outside of the recharge area for the cave. Prior to construction of the field two dye traces were conducted that demonstrated that the new field area did not contribute water to any of the springs associated with the cave. Most of the funding for the project was provided as a demonstration project by the U.S. Fish and Wildlife Service through the Arkansas Chapter of The Nature Conservancy.

Recovery of the Gray Bat

Tumbling Creek Cave provides habitat for eight species of bats. The Indiana bat (*Myotis sodalis*) has been reported in Tumbling Creek Cave on a limited number of occasions, though early anecdotal accounts indicate that the bat used the cave as a hibernation site in the past. The latest observation was in February 2005, more than ten years since the previous report. With the new cave gate (discussed below), fewer disturbances may lead to more frequent winter use of the cave by these endangered bats.

The gray bat (*Myotis grisescens*) forms large colonies in caves both in the summer and winter, which makes cave protection for this species especially important. The Missouri Department of Conservation's recovery program for gray bats involves many key caves. Tumbling Creek Cave's gray bats have been studied extensively because of their large numbers and the importance of the nutrient input provided by their guano (possibly 95% of the energy input to this cave is from bat guano). Indeed, gray bats may be a keystone species for many

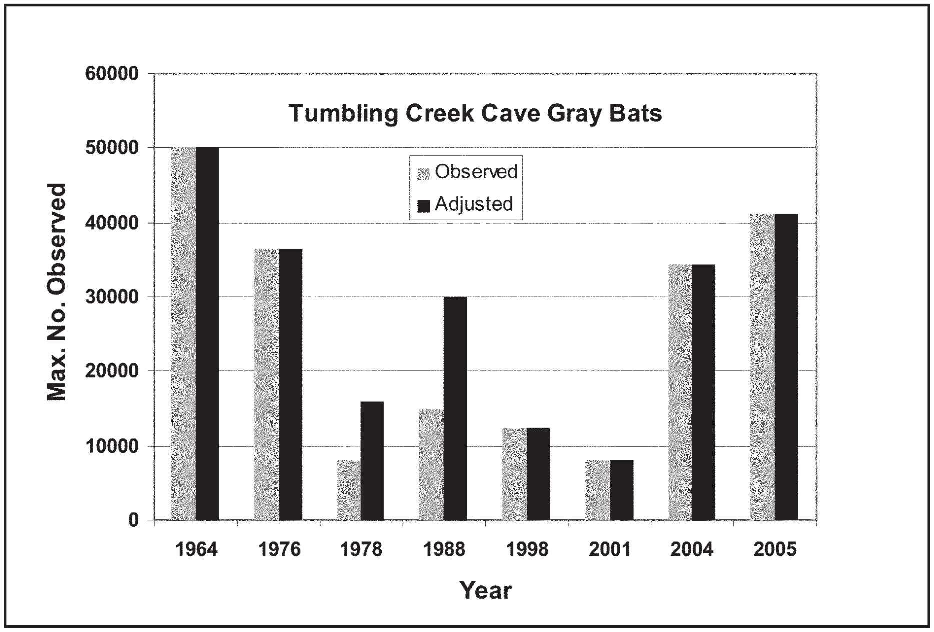

Figure 10. Bar graph showing the maximum number of gray bats observed in Tumbling Creek Cave in mid-summer, after the young are volant. The estimates for 1978 and 1988 were in May or June, and and have been adjusted by a factor of two to approximate the number that would have been observed in July–August.

eastern cave ecosystems (Elliott and Ashley 2005, Elliott 2006a).

The earliest known gray bat population estimate at Tumbling Creek Cave was 50,000 by Richard Meyers in 1964, who also observed 135,000 transient grays in September 1969. In 1976 there were 36,000. Over the next 20 years the numbers varied, but generally did not exceed 15,000. The last emergence count before the new gate was built was about 12,000 in 1998 (Figure 10).

Explaining this decline of Tumbling Creek Cave's gray bats is difficult. Elliott *et al.* (2005) think that the contributing causes of the decline might have been (1) grays declined throughout their range and locally over several decades, (2) an internal cave gate may have hindered movements of the bats, (3) disturbance by intruders via the natural entrance (not then owned and protected by the Aleys), and (4) disturbance and decline at the bat's hibernation sites some distance away.

Samoray and Gardner monitored the gray bats from May to October 2004. They used internal visual surveys, guano estimates, and near-infrared video counts of emergences, the "Missouri Department of Conservation Method" (Elliott *et al.* 2006c). This is by far the most intense monitoring effort of this population, and it consequently revealed several interesting aspects of this species' use of Tumbling Creek Cave.

We found large fluctuations in the number of bats roosting in the cave throughout the summers of 2004 and 2005. Emergence counts ranged from a low of about 19,000 in May 2004 to a high of about 34,000 in August 2004. In May 2005 about 29,000 bats emerged, and in August 2005, about 41,000 emerged. This indicates a net increase of 7,000–10,000 in one year, and the gray bats are approaching the population size observed in 1964.

In 2004, the bats had more erratic emergence patterns during the first two months of the study when compared to the final few months, possibly a result of the new gate. Internal surveys of the cave and the fresh guano (as measured with guano-collecting plates on wooden stakes, Figure. 11), revealed frequent movements among several roosts in the cave; a rare observation for this species, which has very strict temperature and humidity preferences.

This in-cave movement prompted Samoray, Gardner, Elliott, and Kaufmann to study the cave's internal temperature variation (Elliott *et al.* 2005, Samoray *et al.* in press). In March, 2005, we installed Onset® Hobo Pro® temperature data loggers on the roost ceilings in the Bat Mobile Room, East Passage, Lower Stream Passage, and Hibernation Hall and we continued monitoring guano plates. When the bats roosted near the data loggers the ambient temperature increased from about 13.5–14.5°C up to 24–30°. The temperature peaks did not overlap, and with the guano plates they indicated that the bats switched roosts at least five times from April to September 2005 (Figures 1 and 12). In the meantime there was minimal human disturbance of the cave. We hope to answer several questions

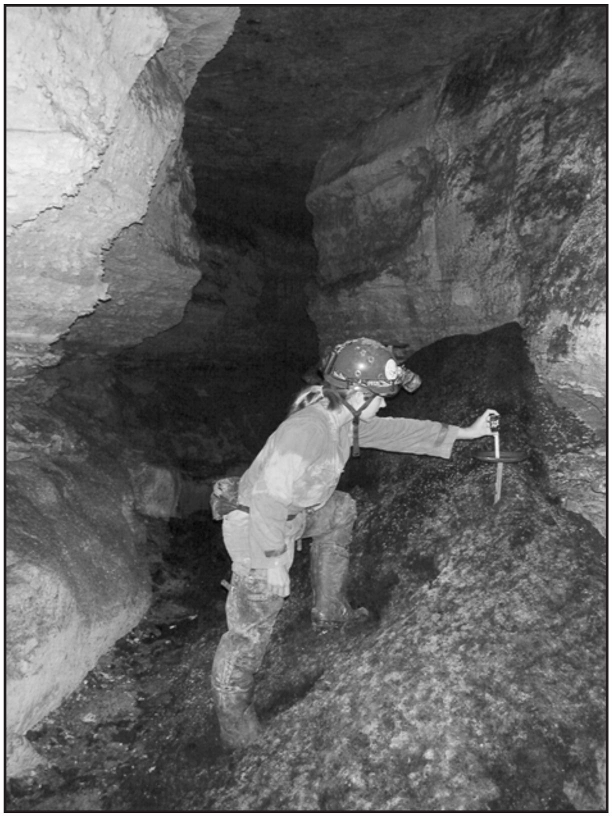

Figure 11. Sara Gardner checks guano accumulated on a staked plate.

about the cave temperatures and the gray bats' use of the cave. Ultimately we hope to predict where the bats may be located at certain times of the year, allowing more cautious visitation to specific areas of the cave.

Cave Protection

A team of 18 conservationists built the world's largest chute gate on the natural entrance in 2004 (Figure 13). A chute gate's function is to keep intruders out of the cave to protect the bats and the other cave resources; the bats fly in and out of the chute. We do not gate a cave for one species, but for an entire cave community. A chute gate is a type developed by Roy Powers of the American Cave Conservation Association since 1996 in Missouri and Tennessee. It allows us to construct gates on some gray bat cave entrances where we could not do so before. A chute gate is used for low, wide entrances, where there is not enough height to build the usual half gate, or flyover gate, for a maternal colony of gray bats. In most of its range, gray bat maternal colonies do not tolerate a full gate that completely covers the cave passage, even when it is properly spaced for bats. However, we can construct a rect-

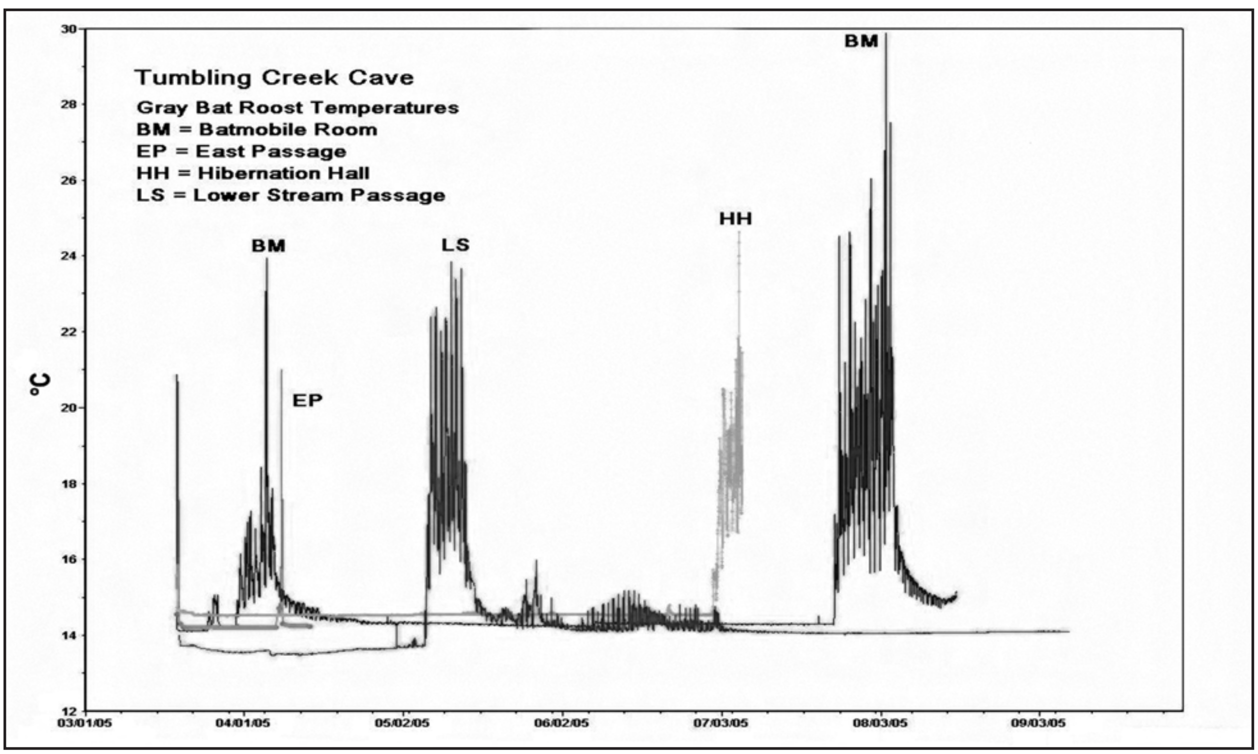

Figure 12. Ambient temperatures measured with Onset® Hobo Pro® data loggers in five gray bat roosts in Tumbling Creek Cave, March–September, 2005. The bats switched roosts at least five times during this period.

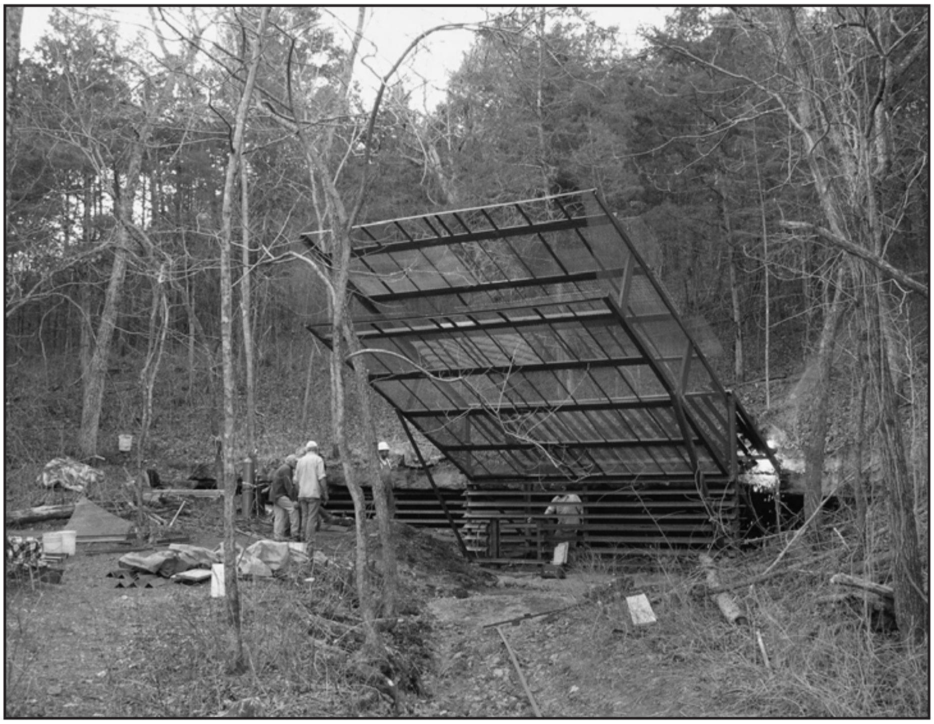

Figure 13. Construction of the Tumbling Creek Cave chute gate, March 2004. Roy Powers and Tom Aley, lower left. The open chute allows pregnant gray bats to use the entrance freely, but excudes human intruders. Bats have increased since the gate was built.

angular metal chute, sheathed in expanded metal (mesh), that angles up from the vertical wall of the gate, high enough to be out of the reach of most intruders.

We built the chute gate in March and April 2004 under the direction of Roy Powers and Jim Kaufmann (Caves & Karst, Inc). Staff from Ozark Underground Laboratory, Missouri Department of Conservation, and some volunteers constructed the 9-ton gate. The Aleys provided food and lodging, saving us travel in this remote part of the Ozarks. The cost of the gate was about $25,000, paid from a Missouri Department of Conservation "State Wildlife Grant." The price does not include in-kind services and volunteer time.

Kenny Sherrill fabricated the strong locking door on the gate. Jim Kaufmann returned several times to complete the welding and add strengthening members to the gate. The gate withstood about 4 m^3/sec. (150 ft^3/sec.) of water outflow in May 2004, a 25-year record. Meanwhile, the old internal gate was removed to expand the flyway for the bats. We observed returning gray bats using the chute gate before it was even finished, a good sign. Our emergence counts from infrared video indicated a large increase in the colony over the 1998 visual count, even before the full maternity season. In August 2005 the population increased further to a peak of 41,153. The gate appears to be a success.

The Missouri Department of Conservation is increasing its efforts to help Missouri cave owners and provide public education about caves and karst. The Department is working with Ozark Underground Laboratory, several government agencies, and the Mark Twain School to replace a sewage lagoon that presently loses about 88% of its contents into the groundwater system that feeds Tumbling Creek Cave. A modern septic system will be installed and the students will learn about karst, groundwater, and caves. Missouri Department of Conservation's new "Cave Trunk" for teachers and conservationists will be available to the school. It contains books, curriculum guides, videos, posters, bat models, and a three-dimensional karst groundwater model that illustrates how interconnected cave systems and the surface of the land can be.

Discussion and Lessons Learned

It is troubling that one of the most protected private caves in the Ozarks, in a rural area with little industry or row crops, still developed such ecological problems. However, the following lessons learned and the methods we have developed will be useful to others restoring cave communities or living on karst.

- Noticeable changes can occur in 2–40 years in a cave and on the land.

• Baseline physical and biological data are extremely important to document trends.

• Keep a good logbook inside the entrance if it is secure. A record of visitors, dates, destinations, work, and observations may be invaluable later.

• Multiple, overlapping studies may reinforce or provide interesting correlations.

• A cave in a remote rural setting may be impacted by poor land use on other property in the cave's recharge area.

• Stream and bat communities are dynamic.

• There are many sources of funding and help.

Acknowledgments

We thank the many researchers, agencies, educators, neighbors, cavers, and volunteers who have worked at Tumbling Creek Cave and Ozark Underground Laboratory, particularly Cathy Aley, David Ashley, Paul McKenzie, and the Tumbling Creek Cavesnail Working Group. Philip Moss kindly prepared the turbidity graph in Figure 9. We are grateful to those who constructed the new chute gate: Roy Powers, Jim Kaufmann, Kenny Sherrill, Cathy Aley, Steve Samoray, Sara Gardner, Philip Moss, Ron Oesch, John Arnold, Denny Dendinger, Richie Myers, Phil Oczkowski, Sam Scherffius, Ralph Scherffius, Julie Stearman, and Mike Wages. Special recognition goes to scientists Jerry Lewis, Paul Johnson, Stephanie Clark, and the late Ken Thomson. Our thanks to Jonathan Beard, Charity Gramm, Michael Carter, and numerous other cavers who have helped with cave restoration. The late Deb Walley, his son Bill Walley, and Jim Aley helped with the cave trail construction. The late Jerry Brightwell conducted heavy equipment repairs on erosion gullies; his son Brad also worked on that project and on a new sewage system that transports all treated sewage effluents out of the cave's recharge area. Tim Snell, The Nature Conservancy, helped obtain funding for the new demonstration sewage system. Art Lange, Karst Geophysics, Inc., conducted geophysical surveys to identify other potential cave chambers.

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THE MISSOURI CAVES AND KARST CONSERVANCY: TWELVE YEARS OF CAVE CONSERVATION IN MISSOURI

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Abstract

The Missouri Caves and Karst Conservancy, Inc. was founded in 1993 by a group of cavers with the intent of purchasing and preserving caves in Missouri. In the succeeding 12 years, Missouri Caves and Karst Conservancy has acquired one property and manages or co-manages four other properties. The primary focus of the Conservancy, however, has been conservation through management, education, and research. In support of this focus, the Conservancy has led or participated in several projects in partnership with various private, state, and federal groups. The Conservancy and the Missouri Department of Conservation have partnered for the construction of several modern angle-iron cave gates and the Missouri Cave Life Survey. Geographic Information System analysis of karst areas has been supported by a Conservation Technology Support Program grant from ESRI and Hewlett-Packard. Recreational Equipment, Incorporated (REI) and the National Park Service have supported various MCKC cave restoration projects. The Missouri Caves and Karst Conservancy has recently partnered with the Missouri Caves Association in applying for a specialty license plate in order to increase awareness of caves in Missouri and to raise funds for various projects. The Missouri Caves and Karst Conservancy and the Missouri Department of Conservation will be co-hosting the 2007 National Cave and Karst Management Symposium to be held in St. Louis, Missouri.

Background

The state of Missouri, located in the central portion of the United States, has over 6,000 recorded caves according to records kept by the Missouri Speleological Survey, and more are found on a regular basis. Three of the four largest metropolitan areas in Missouri — St. Louis, Springfield, and Columbia — are located almost entirely on karst. In the rural areas of the Ozarks, where over 50% of the land is within 4 kilometers of a cave, cave exploration is a very popular past time, especially for those of high school age. It is unusual to speak with an individual who grew up in the Ozarks and who has never been caving. Unfortunately, with such popularity it becomes easy for cultural trends to become entrenched. In many places in the Ozarks, almost ubiquitously, vandalism is very well established practice. A cave near Springfield, Missouri, was open to visitation for approximately ten years before being gated. Despite the low entrance crawlway, several thousand formations were broken and large areas were spray painted in that ten-year period (Beard 2005). That particular cave is now a restoration laboratory.

The Ozark area of Missouri is experiencing a significant population growth. Between 1990 and 2000 regions in southern Missouri grew between 11% and 27% (Missouri Dept. of Economic Development). Such growth trends increase pressure on natural resources — especially those considered recreational. This, compounded with an increasing nationwide trend for personal injury litigation, has resulted in numerous privately owned caves being closed to visitation out of fear of liability. In order to help alleviate threats to and closure of significant caves in Missouri, a group of cavers formed the Missouri Caves and Karst Conservancy, Inc.

Founding and Early History

The Missouri Caves and Karst Conservancy was founded in January 1993, for the primary purpose of preserving significant cave and karst resources in Missouri. H. Dwight Weaver, one of the founders of the organization, addressed the 1995 National Caves and Karst Management Symposium (Weaver 1996). One of the primary topics addressed by Weaver was the identification of significant caves in order to focus conservation efforts of the organization. It is highly important to identify such targets, for without knowledge of a resource it is impossible to conserve that resource. This assessment of significance, however, presupposed the existence of accurate information on the range of cave and karst features within the range of interest. Unfortunately, such a data set is very seldom complete or thorough — and when the range of interest is statewide, the data set is often more incomplete than otherwise. Therefore, Weaver began a major effort to compile a significant caves inventory for Missouri.

A second issue addressed by Weaver was the lack of a popular publication targeted towards cave owners and managers. Missouri has, for many years, had three types of cave and karst related publications: grotto newsletters, the *Liaison* (the newsletter of the Missouri Speleological Survey), and *Missouri Speleology*—a more scientific journal published by the Survey. The The Missouri Caves and Karst Conservancy began publishing a quarterly magazine, the *MCKC Digest* — in 1994. The goal of the Digest was to provide timely and pertinent information to cave managers regarding such things as general cave and karst science, restoration, and management issues.

Unfortunately, publishing a high quality magazine such as the Digest requires a great deal of time, effort, and funding. When a community with a rather limited membership, such as the Missouri caving community, undertakes to publish multiple newsletters, the *Missouri Speleology Journal*, and the *MCKC Digest*; qualified editors and writers become over-used. Lack of material forced the retirement of the second Digest editor. After a fruitless search for a replacement editor and more material, the The Missouri Caves and Karst Conservancy Board of Directors decided to discontinue the regular publishing of the Digest and, instead, adopt a quarterly newsletter which could be assembled quickly after each board meeting and sent to the membership. This has proved to be very beneficial as the majority of the conservancy's resources and manpower were being absorbed by the Digest. The board is now able to keep the general membership updated in a timelier manner and more manpower is available for other projects.

Cave ownership by The Missouri Caves and Karst Conservancy commenced with the purchase of Skaggs Cave, finalized on January 16, 1996. Conservancy member Ronald Jaeger and the owners, Tim and Rena Miller, made this purchase possible. Skaggs Cave has over one mile of mapped passageways and is noted for its speleothems, size, and complexity. The Lake Ozark Grotto and Kansas City Area Grotto of the NSS and other Missouri cavers constructed a gate on Skaggs Cave in 1990 with funding provided by the Mississippi Valley Ozark Region of the National Speleological Society (Figure 1).

Figure 1. Entrance to Skaggs Cave with the spider gate (this gate has been replaced). Photographer unknown.

Cave Projects

Though no additional caves have been added to the ownership list of the Conservancy since the purchase of Skaggs Cave, four more properties have been leased or managed. Cystal Caverns, a formerly commercialized cave in Cassville, Missouri, has been leased by The Missouri Caves and Karst Conservancy since 1999. The cave had been neglected for years and the property logged over. The cave has no natural entrance and the excavated entrance is closed by a concrete block building. When The Missouri Caves and Karst Conservancy leased the property there was a large hole in the artificially closed entrance roof and large piles of trash outside the cave. In order to use the cave for educational tours, the cave had to pass an inspection by the Mine and Cave Safety and Health Program of the Missouri Department of Labor and Industrial Relations. The Missouri Caves and Karst Conservancy was awarded a grant from Recreational Equipment, Inc., to help modify the handrails, fix the hole in the roof, and obtain helmets and headlamps for group tours. Work is continuing on this project. Crystal Caverns is noted for its impressive aragonite needles and calcite formations (Figure 2).

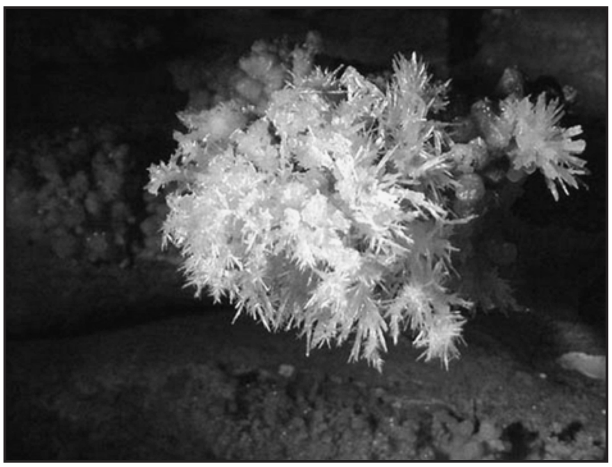

Figure 2. Aragonite needles in Crystal Caverns. Photo by Jon Beard.

Sarcoxie Cave in Jasper County has been managed by The Missouri Caves and Karst Conservancy since its purchase by the Ozark Regional Land Trust in 1997. Sarcoxie Cave is an important site of the threatened Ozark cave fish (*Amblyopsis rosae*) and the bristly cave crayfish (*Cambarus setosus*). This small cave (often referred to as "a cave only a cave fish would love") is closed to visitation except for scientific research.

Dream Cave in Ozark County is managed by The Missouri Caves and Karst Conservancy in cooperation with the Ozark Highlands Grotto in Springfield. Dream Cave is quite interesting geologically. In one passage a large number of stromatolites have weathered out of the bedrock and resemble a motley collection of conga drums (Figure 3). What would otherwise be an easy walking-height passage is a convoluted and uncomfortable belly crawl.

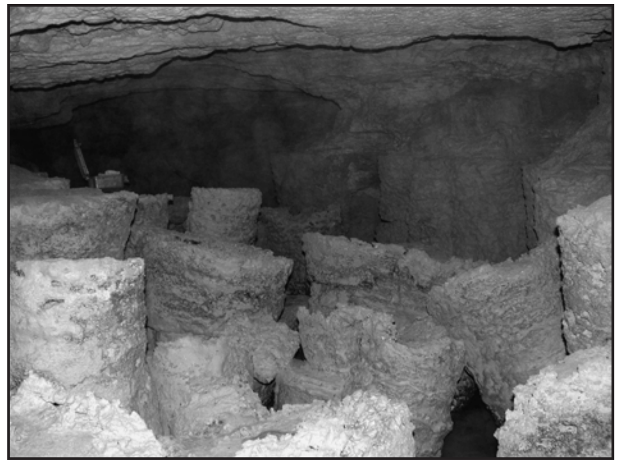

Figure 3. "Conga drum" stromatolites in Dream Cave. Photo by Hal Baker.

The Conservancy's most popular cave, Perkins Cave, Camden County, is privately owned and managed by The Missouri Caves and Karst Conservancy under contract. Perkins was also the site of The Missouri Caves and Karst Conservancy's first in-house cave gating project. The cave entrance is located within 20 feet of a county road just out of sight of the owner's residence and was experiencing an increasing amount of trespassing and vandalism. The landowner requested a gate be installed in May 2003 and asked The Missouri Caves and Karst Conservancy to manage it. The Conservancy manages the cave with a liberal visitation policy and groups who have used the cave for many years have reported an increase in cave life and no additional vandalism or trash accumulation. Perkins Cave is noted for its many natural bridges, striking passages, and as a significant Pleistocene paleontological site.

Bruce Cave in Ste. Genevieve County has been managed by The Missouri Caves and Karst Conservancy since June of 2003 via a request of the previous land owner. This cave is located within a privately owned hunting preserve and is closed to visitation.

Significant Caves List

One of the mission statements of the Missouri Caves and Karst Conservancy is to preserve the highly significant caves of Missouri. However, that begs the question, "what caves are 'highly sig-

Table 1. Significant caves listing criteria used by Weaver (Weaver 2000).

	Criteria		
Category	**Highly Significant**	**Very Significant**	**Above Avg Significance**
Length	> two mi.	> one mile < 2 mi.	> 1000 feet, < 1 mi.
Depth		> 100 ft.	> 40 ft, < 100 ft
Archaeology	Burials, human remains	Recorded excavations, recovered material	Artifacts known
Biology	State or Fed. Listed species	Large reproducing pop. any sp. or many trogs	Diverse and healthy ecosystem
Geology	Classic textbook feature or extensive maze	Multiple levels Outstanding solutional features/speleogens	Uncommon structural features (e.g. fault)
Paleontology	Tracks, claw marks, trails, dens, etc.	Materal removed	Known to have material
History	Famous individual or significant event in MO	Associated w/some industry or historic interest	Notable cultural value or ruins
Show Cave	Long history or currently active	Closed but has potential	Abandoned
Speleothems	Exceptional, unique, etc.	Well decorated	

nificant'?" H. Dwight Weaver not only raised this question but also proposed an answer (Weaver 1996). A monumental nine-year effort by Dwight Weaver, assisted by Jonathan Beard, which involved examining reports on nearly 5,500 caves, resulted in the "Significant Caves of Missouri" list in 1999 and which was published in the *MCKC Digest*, Winter 2000 issue (Weaver 2000). In compiling this list, each cave report and other supporting information as was available were examined for certain items of interest and a ranking for the cave was assigned based on the "value" of these items. The ranks of significance were kept quite simple: above average (AS), very significant (VS), and highly significant (HS). See Table 1 below for a summary of items, values, and significance rankings for those values. It is important to note that each item or category of interest is independent. The presence of a single endangered species, a unique history, or an extraordinary geological feature, for example, would each, independently, result in a ranking of "highly significant" for a cave. Other attempts at assigning significance have included summing groups of features — such as biological, geological, and cultural — and assigning total scores based on the sum of the features. Unfortunately, each method can result in unfair rankings and both lists should be consulted. In the former method, for example, a cave with a broad range of features that are only considered "very significant" would have a ranking of "very significant." In the latter method, such a cave could easily be considered "highly significant" based on the range of features.

The result of this significant cave project was the identification of 250 caves which earned the ranking of "Highly Significant." Many of these caves earn the ranking due to the presence of one or more endangered species. Others have unique archeological resources or a significant cultural aspect.

Other Projects

Though the compilation of the significant caves list was a very great effort, the resource assessment is only as good as that data upon which it is based. Resource inventorying is a very significant portion of any concerted conservation effort and supporting endeavors to increase the value of the data set — whether by volunteering time, expertise, or funding — is often as important as conserving the resource itself. It may, in fact, be more important as information gleaned from such investigations assists other landowners — both private and public — in making management decisions and can lead to a much larger conservation effort than is possible by a single not-for-profit organization. The Missouri Caves and Karst Conservancy has dedicated a major portion of its time and energy in the past 12 years helping to expand and improve the quality and completeness of the data on Missouri caves that help to identify significance and threats.

One of these efforts involved partnering with the Missouri Department of Conservation in the Missouri Cave Life Survey which was supported by a "Partnerships in Wildlife" grant from the U.S. Fish and Wildlife Service. The goal of the survey was to revisit a select subset of caves which had been inventoried 20 years earlier (Elliott and Ireland 2002). In this effort 45 cavers were trained to identify 66 cave species. One result of this project was the publishing of "A Guide to Missouri's Cave Life" booklet by the Missouri Department of Conservation (Elliott 2003).

In addition to the cave life survey, the conservancy has also received a Conservation Technology Support Program Grant from ESRI and Hewlett-Packard to fund geographic information system (GIS) work on cave and karst areas in Missouri. The Missouri Caves and Karst Conservancy also participates in the Volunteer-In-Park Program for the Ozark National Scenic Riverways. In this program three caves have been "adopted" for clean up, monitoring, and, in one case, trail-building.

Recognizing that access to caves must be controlled in order to manage threats from over use and trespassing, The Missouri Caves and Karst Conservancy participated in a cave gating workshop hosted by the Missouri Department of Conservation, the American Cave Conservation Association, and Bat Conservation International in June 2001. The Department of Conservation provided funding for scholarships that were awarded to three The Missouri Caves and Karst Conservancy members (Matt Marciano, Kenny Sherrill, and Jim Kaufmann). The Missouri Caves and Karst Conservancy and Missouri Department of Conservation partnered again for the gating of Kiesewetter Cave in Camden County, a project that also served as a cave gating workshop. The conservancy afterwards purchased specialty tools — a rotary hammer drill, generator, and portable welder — which are rented out to cave gating projects. Sherrill and Kaufmann continued to build gates both for the Missouri Caves and Karst Conservancy and under private contracts.

The gate constructed on Skaggs Cave in 1990 was a very artistic spider web design. These artistic designs, however, though they may be nice to look at can be very detrimental to cave life. They tend to be bat excluders and are often easily breached by vandals. The Skaggs spider web gate was breached several times each year. After gaining experience in building American Cave Conservation Association style angle iron gates, the The Missouri Caves and Karst Conservancy board decided to replace the Skaggs spider gate with a more modern, bat friendly gate.

Recognizing the need for more consistent funding, the Missouri Caves and Karst Conservancy decided to develop a specialty automotive license plate under a program available to Missouri not-for-profit organizations. In order to obtain a specialty plate, a donation of $25 per year is made to the sponsoring organization. A minimum of 200 donors are necessary for the application process to begin. The Missouri Caves and Karst Conservancy partnered with the Missouri Caves Association in this project both to help increase the exposure and ensure an adequate number of applicants. The cost and donations are being split equally between the two organizations. The Missouri Caves and Karst Conservancy board member Bryan McAllister designed the specialty plate (Figure 4) which is still in the approval process.

Furthering the Missouri Caves and Karst Conservancy's dedication to research and education, another partnership with the Missouri Department of Conservation was formed to host the 2007 National Cave Management Symposium. The symposium will be held in St. Louis, Missouri, in October 2007, at the Holiday Inn Southwest — Viking Conference Center and Missouri Department of Conservation's Powder Valley Nature Center.

Figure 4. Proposed "The Cave State" specialty license plate design by Brian McAllister.

Conclusion

The Missouri Caves and Karst Conservancy, Inc., was founded in 1993 for the purpose of conserving and protecting significant cave and karst resources in Missouri. For many years a significant effort of the organization involved the publishing of the award-winning *MCKC Digest*. More recently, however, an increasing amount of effort has been focused on improving the data set for Missouri cave and karst resources, education, and management through avenues other than direct ownership. It is very important for a relatively small organization such as the Missouri Caves and Karst Conservancy to work towards its strengths — in this case an enthusiastic, diverse, and skilled volunteer group. Forming partnerships with other organizations with similar goals, such as the Missouri Department of Conservation, enables both organizations to accomplish projects which would be beyond the scope of either organization individually. Furthermore, recruiting local cavers to help manage or adopt caves in their home area helps make resource conservation less of an abstract concept and more of a local, hands-on project.

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McFails Cave, the Beginning of NSS Cave Ownership and Development of a Model for Interactive Cave Management

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Abstract

At the 1965 NSS Convention in Indiana, the Board of Governors voted to accept ownership of the first NSS cave property, McFails Cave in New York State. To do so, they had to change a long-standing NSS policy of non-ownership of caves. This paper will cover the series of events, some serendipitous and some planned, that led to the purchase of McFails Cave and it's role in changing NSS cave ownership policy. I will also discuss the development of the management strategy, through establishment of the McFails Committee, as a successful model of interactive cave management.

Description

The pit we know today as McFails Hole is located in a heavily glaciated karst terrain four miles (as the bat flies) northeast of Cobleskill in Schoharie County, New York. It is in a woodland of maple, birch, beech, oak, and hemlock in the midst of dairy farms and cropland. The woodland contains several depressions and pits, with intermittent surface streams feeding into many of them, including McFails Hole. The opening is a double pit, the first 60 feet being sloping ledges through the Kalkberg Limestone and a vertical shaft through the Coeymans Limestone formation. The lower 30-foot-deep pit extends into the Manlius Limestone. It opens from a narrow crack in the west end of the floor of the upper pit, and a narrow crack, partially filled with debris and rock fill, bells out into a chamber with its floor covered with rocks and debris. Low passages which extend both ways from the bottom quickly become stream passages. Upstream, the passage becomes a series of narrow fissures partially filled with water that becomes deeper until it eventually fills the entire passage. Downstream the passage is partially filled with washed-in gravel, leaving a low (hands and knees) stream passage that gradually enlarges to a series of stoopways and knee- to chest-deep pools. A near-siphon about 1,400 feet from the entrance was pushed in 1961, opening into 5 miles of mostly large passageway. The Main Passage, after nearly 3 miles, and the Southeast Passage, after 2,000 feet, are water filled. In both cases, diving has yielded extensive additions with continuing water-filled passage. The Northeast Passage, after over 7,000 feet of fairly easy going, has more recently yielded several thousand additional feet of difficult passage. Currently, McFails Cave has about 7 miles of explored passage. (Cullen, Mylroie, and Palmer 1979; Palmer 1979; Evans 1979)

History and exploration

Professor Thomas Alfred McFail, an instructor from Carlisle Seminary, entered a pit known locally as the Ice Hole on July 1, 1854, and was climbing a rope to the surface when he slipped, fell back into the pit, broke his neck, and died. The pit was filled with logs. (Brown 1945) It is believed this is the pit now known as McFails Hole. However, a nearby pit, Wicks Hole (seen from below) is full of large suspended logs which totally block the pit, so it might have been the original "Ice Hole." William E. Roscoe, in the *History of Schoharie County* gives an account of the accident, with several changes in detail. He says Professor Thomas N. McFail (*sic*), met his death at the entrance in 1853 (*sic*), was be-

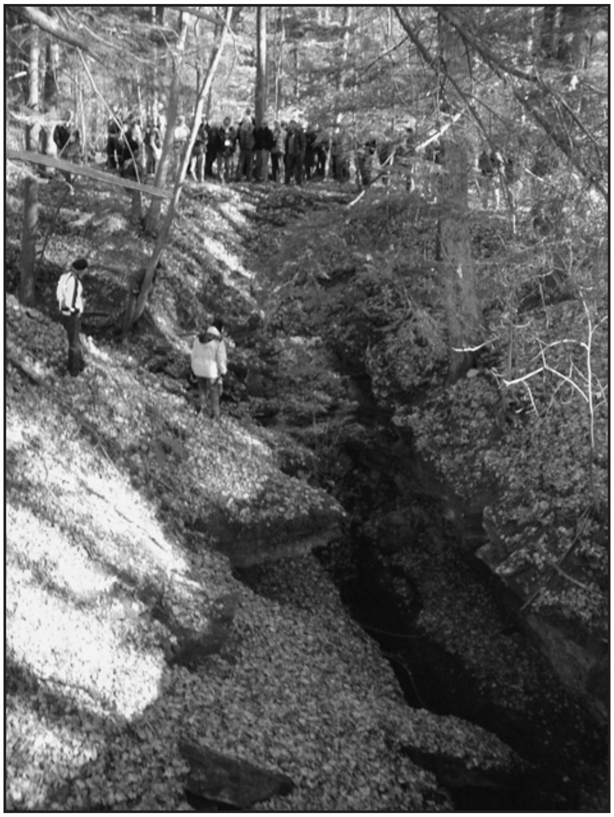


Figure 1. McFails Hole entrance. NCKMS fieldtrip, November 2005. Photo by Fred Stone.

ing drawn up on a rope when he fainted and fell backward, fracturing his skull. Since Roscoe got McFails name and the year wrong, it is quite likely that the other details are also apocryphal. (Roscoe 1882, p 317)

There are only a few mentions of McFails Hole in published records over the hundred years following McFail's death. In 1906 Professor John A. Cook of the New York State Museum, while conducting his survey of caves of the area, was unable to gain entry into the cave presumed to be the current McFails Hole. (Cook 1906) In 1929 a group of cavers with Arthur Van Voris entered the upper pit, and while there, the debris blocking the lower pit collapsed into it. Some members of the group entered the cave, but it is not clear that Van Voris did since his account doubles the depth of the entrance pit. Clay Perry in his book *Underground Empire* summarizes second-hand information about McFails Hole, confusing it with Sellecks Cave and Wolferts Cave, and repeating Roscoe's erroneous account of McFail's death. (Perry 1948)

National Speleological Society involvement with McFails began at the fall Northeast Regional Association get together on November 8, 1958, when 18 people explored the entrances around McFails Hole. This trip was written up in a 1958 *NSS News*. Russell Gurnee (NSS 1907) and Dick Anderson (NSS 2301) went downstream about 250 feet from the base of McFails Hole Pit to the keyhole. Except for McFails Hole itself and Cave Disappointment, other nearby pits were named for members of the group; Acks Shack for Earnest Ackerly (NSS 258L), Featherstonhaughs Flop for James D. Featherstonhaugh (NSS 1695), Hanors Hole for Charles J. Hanor (NSS 1124) and Wicks Hole for Wesley S. Wickenhofer (NSS 1230). (*NSS News* 1958)

On July 24, 1960, Norm Olsen (NSS 4872), Peter Van Note, Charles Marr, and Joe Homburger reopened the lower McFails Hole Pit and explored about 400 feet upstream and 1,000 feet downstream (to a "Syphon Pool"). Between August and October 1960 the above group with George and Richard Smith mapped the cave, and published a report in the *NSS News* under the title "Howe Cave Project." (Olsen 1961). Other northeast cavers began exploring McFails, including a trip by Art Palmer (NSS 4059), Marlin Kreidler and Hugh Blanchard upstream 1,800 feet to a sump 31 feet deep.

My own involvement with Cobleskill caves began with my 8th grade school trip to Albany in 1951. It was a long trip from my home town of Marathon, New York, about four hours each way. On the way back, we stopped at Howe Caverns. It was my first cave and I wanted to see more, but I didn't have another chance until I met Lyle Conrad at Cornell University. In 1958 he invited me on a Cornell Outing Club trip to go caving in Centre County, Pennsylvania, followed over the next few years by trips to West Virginia, Virginia, and Tennessee. In spring 1960, my father had to have an operation, so I took a term off of college to stay on the family farm and milk the cows. I could only go on trips between milkings, so I decided to check out the caves of New York described in Clay Perry's *Underground Empire* (which I had listed and indexed in a three ring binder). My first trip was with my brother, Ben, and a college buddy, George Gesslein. We drove down Route 20 and I noticed the sign for the town of Carlisle, which I recognized from Perry's book. I turned right on the next road, and came to Carlisle Center. Just beyond, we

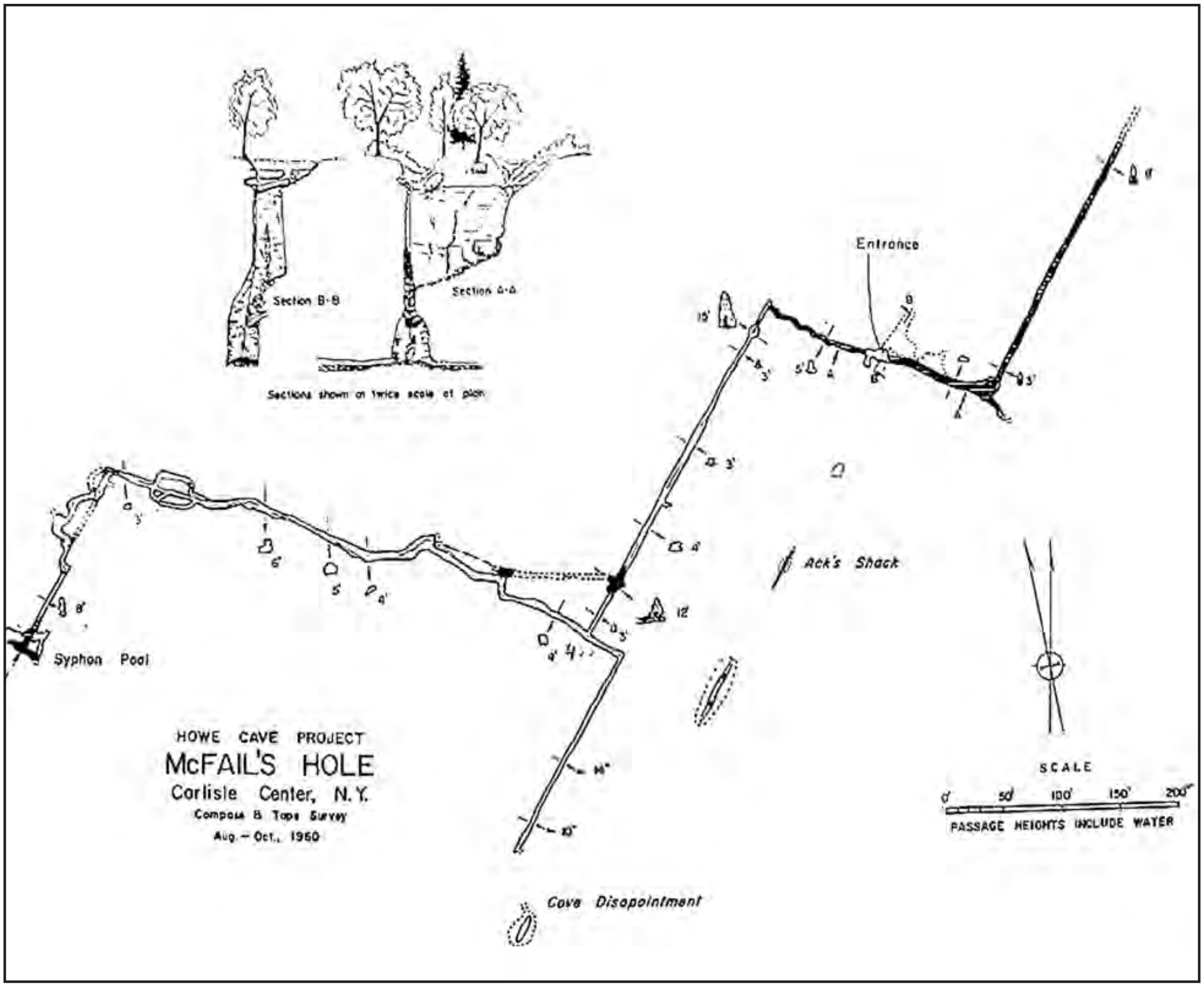


Figure 2. Map of McFails Cave by Norman Olsen, NSSNews, January 1961.

noticed the entrance of Youngs or Runkles Cave on a low ridge behind a house. We stopped and talked to Mr George Loeser. He said we could explore Youngs Cave (he didn't actually own it). After the short walk through the cave, we went back to talk with Mr Loeser. He told us about the cave in his woods, "da McFails Cave." He said some cavers were mapping it. He told us we could explore it, but we would need ropes — and to be careful, it was dangerous. We were back a few weeks later and again stopped first to ask Mr Loeser's permission. This time, I brought a relatively new 3/8-inch manila hay rope. With George Gesslein on belay, I did a hot seat rappel into the upper pit and peered into the crack that opened into the lower pit, but didn't have enough rope to enter it. Then I tied the rope around my waist and chimneyed out of the upper pit with George belaying. Once, I pendulumed off the slippery walls, and nearly dissected poor George, but he held me, and I made it out without repeating McFails fatal plunge.

I was back on October 28, 1960, leading a Cornell Outing Club trip. We arrived in the evening, rigged cable ladders, and Spencer Weart, Mal Churchill, and I entered McFails lower pit on belay by Nancy Cadwallader (later Nancy Howarth, NSS 8628). We explored the stream passage, a hands-and-knees crawl, downstream 300 feet to a waist-deep pond which sumped to the right. Straight ahead, a narrow fissure crawl passage continued for 20 feet, the Keyhole. On the far side, the passage went left to a low sandy crawl (toward Disappointment Cave) and right to rejoin the stream. The stream passage was larger, 5 to 6 feet high with good air flow, but we had run out of time. Due to a communication problem, Nancy remained on belay from 11:00 p.m.

until we returned at about 2:00 A.M.

I came back later that fall (Thanksgiving weekend) with my brother Ben, but the ground was frozen and the streams were flowing into the woods. At the bottom of the lower McFails Pit there was a raging stream, and the passages were flooded. Ben and I were back on June 3, 1961, and found the stream back to its "normal" level. We explored downstream, and reached Olsen's "Syphon Pool." We searched the walls around the pool, and found a bypass passage. Three hundred feet further downstream, past a "Swiss-cheese" section, we slid down a clay bank into a large pool. The ceiling sloped down to water level, and waves made a "phoop-phoop-phoop" sound as they splashed against it.

On October 8, 1961, I was back with Spencer Weart and Ken Miller with the goal of trying to find a way past the large pool. We were wearing life preserver vests. There were several possibilities. First, we swam down a right-hand passage until it became water filled. Next we tried straight ahead, but the ceiling quickly dipped below the water level. Then I tried the left side passage. The ceiling nearly reached the water level, but a few inches of air remained. After about 50 feet, the ceiling began to rise, and I emerged into a large stream passage. I talked Spence and Ken through the sump, and we were ecstatic as we explored 4,600 feet of clean-rock virgin passage, turning back in a passage 30 feet high and 10 feet wide.

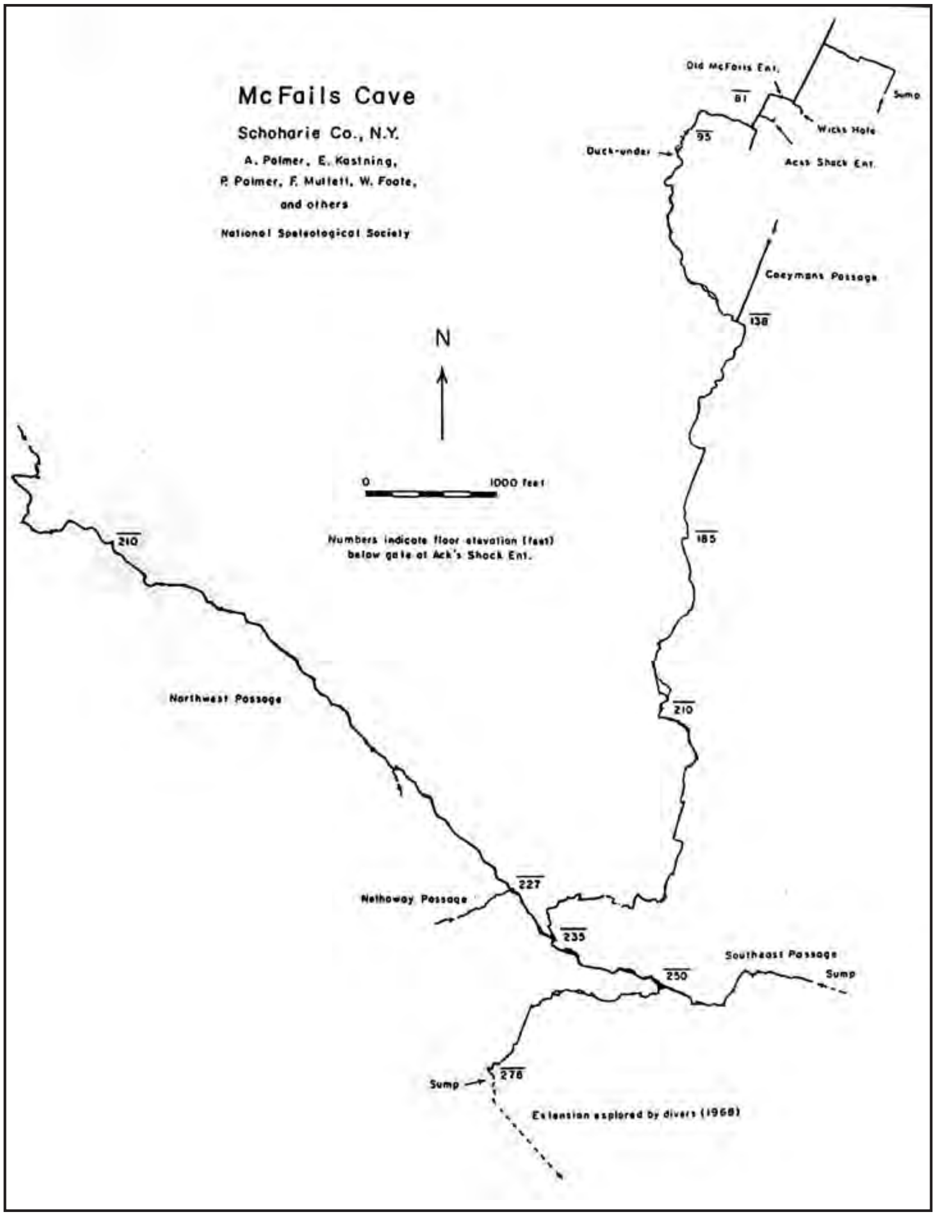


Figure 2. Map of McFails Cave by Art Palmer.

Over the next year, I led Cornell Outing Club and other Northeast Regional Organization cavers [among others Ben Stone, Bill Bousman, Tom Hallinan, Nancy Coles, Spencer Weart, Frank Howarth (NSS 6344), Willy Crowther, Lyle Conrad (NSS 4951)] in exploring the main downstream portion of McFails, including the Northwest and Southeast Passages, totaling over 5 miles of cave passage. In Spring 1963 Art Palmer, Spencer Weart, and I mapped about 3 miles of downstream McFails in a 20-hour trip.

The rocks filling the lower pit of McFails Hole entrance which had always been precariously held by a large basal chockstone, began to collapse in earnest in July 1963. Frank Howarth and I had just returned from an 18-hour "Friday the 13th" trip, collecting cave invertebrates and trying to push the end of the Northwest Passage. As I was prusiking out of the crack at the top of the lower pit, the large (picnic table-size) chockstone suddenly fell from the base of the rock fill directly in front of me. Frank, waiting in the lower pit, heard a scraping sound and dove into the stream passage, narrowly escaping the rock which landed with an immense crash, neatly cutting the goldline climbing rope (several feet of rope are still under the rock).

We decided to look for an alternative entrance, and on August 10, 1963, Frank Howarth, Elean Benjamin, and I began digging the passage at the base of Acks Shack that aimed toward a side passage in McFails. The passage was filled with sand and gravel washed in by periodic flooding, but with a few inches of air space. Other group members checked Wicks Hole and tried digging the sand-filled crawl from the keyhole toward Cave Disappointment, without success. The Acks Shack dig was completed on August 17, with Art Palmer, Chuck Porter (NSS 5330), and crew entering the McFails entrance and digging in the side passage toward the Cornell group who were continuing to dig from Acks Shack. The passage was soon connected, and the 100-foot crawl was used for entry into McFails until the Halls Hole Entrance was opened in 1978. The McFails Hole lower pit fill finished collapsing into the lower pit shortly later while Art Palmer was climbing out, leaving him hanging from his Prusik rope.

In 1968, cave divers Allen Budreau and Brian Pease with a crew from Boston Grotto dove the sump at the end of the Main Passage, and after 300 feet, found about 800 feet of air filled passage (they dubbed the "Boston Passage") to a second water-filled section. Bob Jefferies penetrated an additional 300 feet past the second sump. (Budreau and Allen 1968)

During Sepember and October 1984 Paul Rubin (NSS 14675) and crew, after several trips to enlarge the tight squeeze at the end of the Northwest Passage, pushed through and explored about 1,500 feet of challenging passage to the Asia Dome and several hundred feet of partially water-filled crawl passage beyond.

Paul Rubin and crew took diving gear into the Southeast Passage on July 13, 1985. John Schweyen went through a near siphon and a 50-foot total siphon and found 100 feet of air filled passage, but ran out of dive line in going water filled passage. This passage has not been further pushed since then.

Recently, in 2005, an additional half mile of passage was explored beyond the Asia Dome by Cornell University cavers, with going passage heading toward Sellecks Cave which belongs to the Northeast Cave Conservancy.

McFails Purchase

The discovery of a major cave in New York presented a dilemma to the Cornell cavers. The cave was highly vulnerable to vandalism, and presented dangers for inexperienced cavers with its vertical entrance and long sections of water passage at 46° F. It also has some of the largest bat populations in the Northeast. Initially, we decided to put a moratorium on publications about McFails, and this provided us some time to look for more positive protection.

One idea we began exploring was the possibility of purchase of the cave and making it a conservancy. Direct purchase for preservation had already been done with the Indiana Cave Conservancy. However, there were closer models of cave purchase in the area. Judge James L. Gage of Esperance, just 8 miles from McFails Cave, owned Gage (Balls) Cave and Schoharie Caverns. A local caver, Jack Childs, had purchased nearby Onesquethaw Cave.

The Nature Conservancy had been started a few years earlier, so we wrote them about whether they could take ownership of McFails. In their response, they said that they didn't have funds for the purchase, and they encouraged local groups to purchase and manage properties.

On December 30, 1962, a group of Cornell cavers including Ben Stone, Jack Hayes, Frank Howarth, and I decided to have a trip into McFails Cave during a severe blizzard (I cannot remember what our rationale might have been for this clearly ridiculous idea). A nearby farmer called a Civil Defense Rescue of the group and we emerged to find the snowy woodland full of dozens of fire departments, none of whom had any vertical or caving gear. Following this bogus "rescue," local residents wanted to seal the caves to prevent risk of future caver accidents.

Frank Howarth and I went to talk with George Loeser. Loeser, a retired New York City news vendor living with his aged mother, wanted to keep the cave open to cavers to "keep the young people off the streets." During our discussion, we noticed he was looking at a catalogue for small snow plows. He was having trouble keeping his driveway shoveled during the heavy snow storms that winter. He wanted a small tractor and snow plow that would cost $600. I pointed out that with the money from selling the cave, he would be able to buy the tractor. However, Loeser didn't want to reduce the resale value of his land by selling the woodland.

We continued to talk with Loeser during 1963. An important point for him was that he didn't want any one group to prevent other cavers from enjoying the cave. A critical turning point came when Loeser asked "Isn't there a cavers' organization that could own the cave and take charge of cavers visiting the cave?" Cornell Grotto, active in the 1950s, had just been reorganized so I was able to answer Loeser, "Yes, the National Speleological Society, and we have a local chapter at Cornell."

Finally, Loeser agreed to sell us the cave, if we could keep the land to the absolute minimum. We did a preliminary surface survey, and were able to reduce the land area to a long "dog-leg" strip of one acre. It included most of the entrances, but excluded Wicks Hole (which was a closed depression at that time, but has recently begun to re-open).

Cornell Grotto members attended the Spring 1964 Northeast Regional Organization meeting and discussed McFails cave, the status of exploration and the purchase. Northeast Regional Organization agreed with the non-publication policy until the cave could be protected.

I had been corresponding with NSS President Russell Gurnee about cave ownership. Gurnee advised that we consult with the NSS Legal Counsel, Judge James Gage (the local cave owner from Esperance, only 8 miles from McFails). Gurnee also discussed the liability problems, which had prevented NSS from owning caves up to that time. On August 12, 1964, Frank Howarth and I met with Judge Gage to discuss the McFails purchase.

Later the same day, we met with George Loeser and his council, Nellie Gorden, at her office in Cobleskill. Loeser said he wanted $1,000 for the one acre of land, substantially higher than the $600 he had mentioned earlier (he decided he needed a larger tractor). We would also pay surveying and legal fees. We blinked and said "Agreed," with no idea where we (both graduate students) would find that much money.

I wrote James Gage outlining the main points of the purchase: (1) Loeser is willing to sell to an organized caving group who will agree not to close the cave to other cavers. (2) Loeser has agreed to sell the cave to the Cornell group as representing the NSS. (3) Problem of mineral rights — how can we protect the cave from mining? (4) If we buy land around the entrances and cave rights to Loeser's property, we still don't own the cave under other properties.

On September 10, 1964, I borrowed $1,000 from the First National Bank of Cortland for the McFails purchase. Dr William A. Wimsatt, the noted bat specialist from Cornell University, co-signed the loan. Since I had no job or collateral at the time, the small-town bank approved the loan based our family name (my father, Gerald Stone, a Cortland County dairy farmer, had a reputation for re-paying his loans).

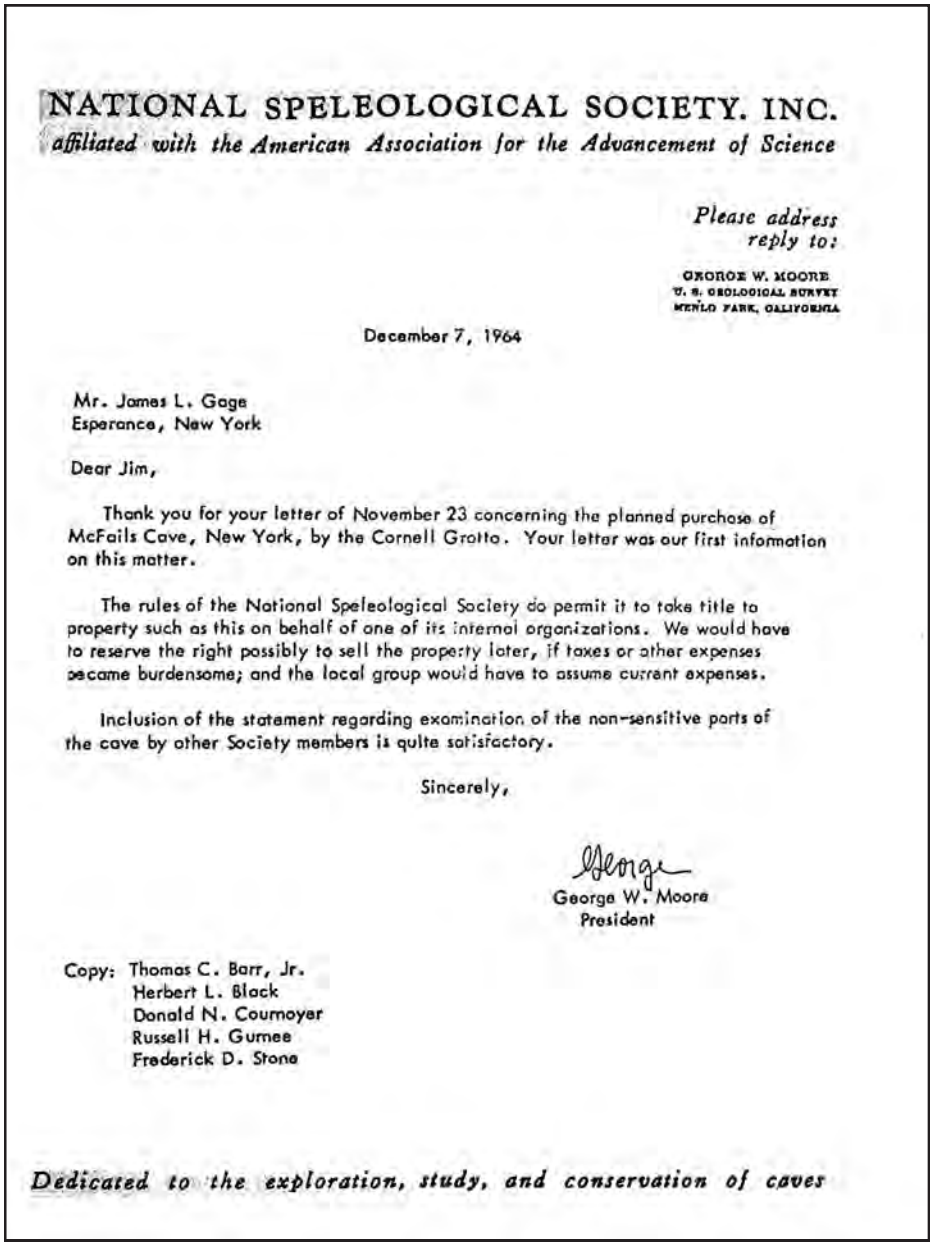
Late in September I left for Viet Nam for two years work with International Voluntary Services. Frank Howarth continued working on the McFails purchase until he and Nancy departed in late 1985 for International Voluntary Services work in Laos. I paid about $750 of the McFails loan from my $75 per month stipend with International Voluntary Services, and Frank and Nancy Howarth paid the rest from their International Voluntary Services stipends.

We hired Cobleskill Surveyor Floyd E. Snyder to survey the one acre of land in Loesser's woods and the right-of-way. On October 22, 1964, Mr Snyder submitted the survey of the land and his bill for $145.40, paid by the Cornell Outing Club. His survey was later found to contain several errors, and the land had to be re-surveyed.

On November 9, 1964, Loeser's lawyer, Nellie Gordon, wrote James Gage enclosing copies of the title search and survey. She also said the Mr. Loeser was concerned because "Harvard spelunkers" had written him saying they were afraid they would be barred from the cave. She enclosed a statement to be included in the deed, stating that the NSS would permit any member of the NSS or its affiliates, upon application in writing, to visit and explore the caves. A modified statement was included in the final deed (below).

Frank Howarth re-wrote the "permission clause" with advice from Judge Gage to allow the NSS to restrict entry into areas with cave species, vegetation, or minerals that might be endangered by entry.

On November 23, 1964, Judge Gage wrote to the NSS informing them that the Cornell Grotto had tentatively agreed to purchase McFails Hole and asking whether the NSS would take title to the property. NSS President George Moore responded on December 7, 1964, stating that the rules of the NSS permitted it to take title to a property on behalf of one of its internal organizations. A local group would have to assume current expenses. This letter allowed Howarth to proceed with the purchase.



NATIONAL SPELEOLOGICAL SOCIETY. INC.

affiliated with the American Association for the Advancement of Science

Please address reply to:

GEORGE W. MOORE
U. S. GEOLOGICAL SURVEY
MENLO PARK, CALIFORNIA

December 7, 1964

Mr. James L. Gage
Esperance, New York

Dear Jim,

Thank you for your letter of November 23 concerning the planned purchase of McFails Cave, New York, by the Cornell Grotto. Your letter was our first information on this matter.

The rules of the National Speleological Society do permit it to take title to property such as this on behalf of one of its internal organizations. We would have to reserve the right possibly to sell the property later, if taxes or other expenses became burdensome; and the local group would have to assume current expenses.

Inclusion of the statement regarding examination of the non-sensitive parts of the cave by other Society members is quite satisfactory.

Sincerely,

George
George W. Moore
President

Copy: Thomas C. Barr, Jr.
Herbert L. Black
Donald N. Cournoyer
Russell H. Gurnee
Frederick D. Stone

Dedicated to the exploration, study, and conservation of caves

Figure 5. Letter from NSS President George Moore that allowed Cornell Grotto to proceed with the purchase of McFails Cave for thge NSS.

Frank Howarth attended the Spring 1965 Northeast Regional Organization meeting and discussed the McFails purchase with NSS Board of Governors member Dick Anderson, following up with a letter on May 18 enclosing copies of the correspondence with James Gage.

Gage sent Howarth a copy of the revised deed on June 12, 1965, forwarded it to Miss Gordon for Loeser's approval, contingent on the approval of the Board of Governors.

At the 1965 NSS National Convention in Indiana, Frank Howarth presented a proposal to the Board of Governors that NSS accept ownership of McFails Hole. Frank was assisted by Russell Gurnee, Dick Anderson, Eugene Vehslage, and Ross Eckler (among others). The Board of Governors agreed that NSS could accept ownership, with the stipulation that a local NSS group take management responsibility and provide liability insurance. Cornell Grotto initially agreed to manage the McFails property while the McFails Cave Committee was established as an NSS internal organization, with representatives from each of the Northeast

Regional Organization grottos. The idea for this committee had been discussed during the previous three years in correspondance between me, Russell Gurnee, and several other members of Northeast Regional Organization and the NSS, including Lyle Conrad, Don Cournoyer, Dick Anderson, and Gene Vehslage. The deed for the McFails purchase was recorded August 2, 1965, in the Schoharie County Courthouse, between George Loeser and the National Speleological Society.

McFails Deed: Major points:

- Purchase includes a right of way for right of passage by foot, vehicle, or otherwise approximately 50 feet wide from the highway along the border of Loeser's land.
- Approximately one acre of land containing the entrances of McFails Hole, Acks Shack, Wicks Hole, Cave Disappointment, and a portion of the Hanors Cave sinkhole.
- The purchaser agrees not to destroy or damage farm lands, buildings, fences, and the seller agrees not to destroy or damage any of the caves by surface activities on the remaining farm lands.
- The purchaser agrees to permit any member of the NSS or its affiliated organizations, upon application in writing, to enter, visit, and explore the caves, reserving the right to supervise the sections of the caves or restrict exploration of such sections which contain specimens of animal, vegetable, or mineral substances which would be endangered by such visit or exploration.
- After the first 155 feet from the highway, the purchaser shall use vehicles on the right of way only for transport of heavy equipment. At no time shall the purchaser permit such vehicles to park on the right of way, unless there is a breakdown, in which case they will be removed within 5 hours. The purchaser agrees to block the right of way approximately 155 feet from the highway, and to erect a sign forbidding driving beyond that point except as above limited.

Signed by George Loeser on the 2nd day of August, 1965.

Halls Hole Entrance

Warren Hall (NSS 17679) and crew, dug the Halls Hole entrance into Coeymans Dome on August 13, 1978, reducing the distance to and from the far reaches of the cave by about 3/4 of a mile. Since the NSS owns only the cave entrances (and mineral rights that affect the cave under the former Loeser land), purchase of any additional entrances is the only way of controlling access to the 7-mile-long cave. Fortunately, with rapid work by Bob Addis, the Tillapaugh family, who currently own the Loeser property, agreed to sell the new entrance to the NSS. The Board of Governors voted

Figure 6. Halls Hole enrrance, NCKMS fieldtrip, November 2005. Photo by Fred Stone.

to purchase 0.89 Acres around the Halls Hole entrance and right of way from the McFails property for $200.

Liability and insurance

Now that NSS owned McFails entrance, the biggest concern was liability. Cornell Grotto had agreed to purchase liability insurance. Howarth and Ted Sobel from Cornell met with insurance agents in fall 1965. The agent for Jaquin & Company inspected the McFails property and wrote two pages of recommendations, including fencing and posting the land and having cavers sign a waiver before entering caves. Jaquin's annual premium of $633 would cover $100/300 million bodily injury and 50 million physical damage. This was way beyond what Cornell Grotto members could afford, so they did not purchase it.

On November 6 1965, Howarth wrote The Nature Conservancy asking about their policy on liability insurance on their land. Herbert Hiller from Nature Conservancy answered that they have a blanket policy for all their land. He said $600 seems very high.

NSS legal counsel recommended closing the cave until liability insurance could be purchased. During 1966, Cornell Grotto placed posted signs near the entrances of McFails Hole, Acks Shack, Hourglass Sink (Featherstonaughs Flop), Cave Disappointment and Hanors Cave stating that persons found on or in them would be guilty of trespassing and subject to arrest and fine. Scott Robertson, Cornell Grotto Chairman, wrote to the Northeast Regional Organization on October 15, 1966, informing them of the cave posting.

On December 15, 1966 Tom Barr, President of NSS, wrote Cornell Grotto to find out whether the purchase of McFails had been completed, taxes paid, liability insurance purchased, and a gate constructed. G. Warren Smith, responded that although Cornell had paid for insurance inspection, the Grotto did not have funds for liability insurance. Russell Gurnee and other NSS administrators also tried for many years to purchase liability insurance, without success.

Gage wrote Gurnee and Cournoyer in June 1967 citing relevant sections of New York law dealing with landowner liability. In summary, landowners were not liable for injury or death to trespassers on land posted according to the state regulations. This regulation was given the ultimate test in the following year.

Another death in McFails Cave and legal responses:

A group from Mohawk Community College entered Acks Shack during spring snow melt in 1968, using an inadequate rope. Gerald Alderman was unable to exit the cave, and became stuck and died during the rescue attempt by the Carlisle Fire Department. Remaining members were fined $25 each for trespassing, due to the trespass signs. No law suit was filed, making an important precedent for landowner protection on posted land with cave entrances.

Following threats by local people to blast the cave shut, NSS ownership or not, in September 1969 Scott Robertson, Ben Stone, and a Northeast Regional Organization group installed a gate at the top of Acks Shack pit. The gate was left open until December first, then locked shut. Copies of the key were left with Carlisle Fire Chief Ernie Bywaters, with instructions that NSS groups would inform him before entering McFails. The posted signs gave his name and phone number, and cavers were required to have a letter from the designated NSS representative allowing them to enter the cave. In spite of the signs, Chief Bywaters intercepted several groups attempting to enter McFails Cave without permission over the next several years, and they were arrested and fined.

The posted signs, fences, and Acks Shack gate, with the enforcement of Chief Bywaters, continued to be the most effective deterrent to cave entry.

National Speleological Society and Northeast Regional Organization:

Tom Barr set up the first NSS Committee on McFails Cave January 30, 1967, with Russell Gurnee, Chairman, and members Warren Smith, Cornell Grotto; James L. Gage, NSS Counsel; and Don Cournoyer.

Cornell Grotto, working through the Northeast Regional Organization, continued to provide local management decisions. The Northeast Regional Organization chairman took a major role in Cornell Grotto:

1. 1965: Frank Howarth until he left for Laos (Cornell Grotto)

2. 1965: Ted Sobel (Cornell Grotto)
3. 1966: Scott Robertson (Cornell Grotto)
4. 1967: G. Warren Smith (Cornell Grotto)
5. 1968: Alan W. Myers (Cornell Grotto, Northeast Regional Organization Chairman 1966-1968)
6. 1968: Ben Stone (Cornell Grotto, Northeast Regional Organization, McFails Committee

Al Myers wrote the Northeast Regional Organization Grottos in April, asking that each grotto appoint one member to a McFails Committee. The committee was established at the 1968 spring Northeast Regional Organization meeting, with Ben Stone (Cornell Grotto) chairman, Wayne Foote (Met and Mohawk-Hudson Grotto), Ernst Kastning (Met and Mohawk-Hudson Grotto), Dave Goldman (Met Grotto), Alan Budreau (Boston Grotto), Peter Williams (Boston Grotto), Chuck Porter (Berkshire Grotto), Brian Pease (Central Connecticut Grotto), Chuck Hogan, and Ron Morris present. The main item was a threat that Al Polizzi was financing a survey of McFails by Steve Egemeir and John Merriman for the purpose of excavating an entrance and commercializing the cave. Fortunately, he never followed through with this scheme. (Budreau 1968)

The Northeast Regional Organization McFails Committee permitted all of the northeast grottos to participate in the development of management policies for the McFails property, and also provided NSS cavers an opportunity to seek permission to enter McFails Cave so long as they adhered to the policies of the McFails Committee. This model of interactive cave management led to development of policies responsive to cavers and cave scientists, while incorporating safety and conservation measures.

Wayne Foote, Northeast Regional Organization secretary-treasurer, corresponded with NSS administrator Don Cournoyer during fall 1969 about efforts to get title insurance for McFails. Foote contacted Edwards Insurance Agency (with Hartford Insurance), but they declined to offer insurance. Cournoyer responded that NSS had purchased title insurance on McFails for $5,000 from Lawyers Title Insurance Corp., New York, New York. Lawyers have the abstract of title and title number on file.

Cournoyer had also purchased liability insurance for both McFails land and Huntsville land, for $89/year, 250/500,000 bodily injury and 100,000 physical damage. However, in December 1969, Young and Simon, the NSS insurance agency, cancelled the insurance policy. In spite of continuing efforts over the years to get liability insurance, no insurance company has agreed to provide affordable insurance up to the present. However, New York laws did provide adequate landowner protection, and this has been strengthened by a recent change in New York State landowner liability law that specifically lists caving as an exempted activity, effectively rendering the need for liability insurance a moot issue.

At the November 1969 Board of Governors meeting in Cobleskill, Wayne Foote gave an extensive report on McFails Cave on behalf of the Northeast Regional Organization. He outlined the McFails Cave Project, to encompass a detailed survey of the cave, and geological, hydrological, biological, and historical studies. This was the beginning of the next phase of McFails management, in which a series of McFails cave managers from the northeast area headed the Northeast Regional Organization McFails Committee (which became the NSS McFails Committee). Many northeast cavers worked on the McFails project, including Jon and Dody Dunning who studied the bat population, Art and Peggy Palmer, Ernst Kastning, and John McElroy who surveyed and studied the geology.

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THE OREGON CAVE CONTROVERSIES AND THE NATIONAL COMMISSION ON RISK ASSESSMENT AND RISK MANAGEMENT

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Abstract

Since the 2003 National Cave and Karst Management Symposium, the ferocity of controversies at Oregon Caves National Monument has diminished but deterioration of the cave under National Park Service management has begun to attract newspaper attention. The "spelunker tour" through a paleontological site has been deferred pending a new cave management plan. Several erroneous and misleading publications have been withdrawn from general distribution and from the monument's bookstore. Ludicrous misinformation persists in the Monument's "Official Map and Guide," however, and even more extensively in the guides' patter. In July 2005 at the NSS Convention I discussed the cave's geology with particular reference to the geological misinformation which has been promulgated for about 20 years.

Despite this vigorous misinformation, it is clear that Oregon Caves National Monument no longer meets expectations for continued status as a unit of the National Park System. It should be transferred to the USDA Forest Service, the Oregon State Park System, Josephine County, or to a private operator. Meanwhile, however, recommendations of the National Commission on Risk Assessment and Risk Management should be applied to the forthcoming cave management plan. These include risks both to humans and to the environment, with emphasis on such constructive concepts as avoidance of "command and control" decisions and involvement of "stakeholders" such as cavers throughout the evaluation and management process. In addition to their potential role at Oregon Caves National Monument, their application at Mount St. Helens in 1980 would have saved some 50 lives and much controversy about access for study of its caves after the eruption. Similarly in 2005, their application would have prevented the current controversy about alleged but undemonstrated carbon dioxide in caves of Kilauea Caldera, Hawaii. The National Speleological Society should support widespread use of these principles.

Introduction

In general, only examples of good cave management are presented at National Cave and Karst Management Symposiums. But to protect caves and cave resources, bad cave management practices must also be included occasionally. This paper has two purposes:

(1) To identify Oregon Cave as a site-specific example of harm resulting from bad cave management: harm to the cave, harm to Oregon Caves National Monument, and harm to the National Park Service as a whole.

(2) To introduce the cave management community to comparatively new Federal standards of risk assessment and risk management. These published standards may be useful in preventing future bad cave management. Because of its risks

to both the cave and to the public, cave management is largely risk management.

1918 National Park Service Standards and Their Application to Oregon Caves National Monument

The first clear, detailed standards for units of the National Park System were promulgated by Interior Secretary Franklin K. Lane in 1918 (Lane 1918, quoted in Unrau and Williss 1983). They are vigorously asserted today in ParkWeb, an active National Park Service Web site which includes Unrau and Williss (1983) in full. These standards include (but are not limited to):

- "The national parks must be maintained in absolutely unimpaired form for the use of future generations as well as those of our own time";
- "Every activity ... is subordinate to the duties imposed upon it to faithfully preserve the parks in posterity in their natural state";
- "In the construction of roads, trails, (and the like), particular attention must be devoted always to the harmonizing of these improvements with the landscape";
- "In studying new park projects you should seek to find 'scenery of supreme and distinctive quality or some natural feature so extraordinary or unique as to be of national interest and importance ... distinguished examples of typical forms of 'world architecture'... such as the Grand Canyon."

Unfortunately Oregon Caves National Monument was tacitly exempted from these standards from 1934 to the present.

Short History of Oregon Cave–1934

In 1918, Oregon Cave and tiny Oregon Caves National Monument had been administered by the USDA Forest Service for nine years. If anyone had considered them in the context of the standards just cited, the likely conclusion would have been that they met the standard on harmonization but none of the others. Although widely advertised regionally and promoted extensively, Oregon Cave clearly was:

- a fun show cave, and
- a notable geological feature of regional interest, not a feature of national significance.

Unquestionably it suffered from overuse and inadequate protection, but the brand-new (1916) National Park Service expressed no interest in making it a unit of the National Park System. In 1934, 16 years later, these still were true. Yet in 1934, President Franklin Delano Roosevelt used a classical "command-and-control" decision to transfer it to a flabbergasted National Park Service: a Presidential Proclamation.

Short History of Oregon Cave 1934–1985

In 1934, the National Park Service was neither prepared to administer Oregon Caves National Monument, nor to protect it (Finch 1934). In retrospect, it could have evaded this unexpected new responsibility as it did for some other lands also transferred to it by the proclamation. Had it done so, it would have avoided much demeaning controversy. But in 1934, the National Park Service was as expansionist as many another bureaus of the federal government. Despite its longstanding standards, it chose to retain the cave and to seek enlargement of the tiny Monument area around its entrance (Finch 1934). The first National Park Service cave management recommendations for Oregon Cave urged "that any changes in the operations of the Caves (*sic*) come by a process of evolution (Finch 1934). And so it was. For half a century the cave was managed much as it had been from 1909 to 1934. More and more it came to look like a worn-out show cave.

Short History of Oregon Cave 1985–present

Rather than being "absolutely unimpaired," Oregon Cave became a shattered husk. Everything breakable on or near the tourist path was broken, even well overhead. Because of the tight, narrow geometry of its passages, recurrent deposits of skin oils and dirt and lint accumulations were inevitable. The last breakable speleothem on the tour route (the beautiful little "Bird of Paradise") disappeared in 1999 — about the time that the cave first was locked securely at night (Halliday and Swofford 2003). Trails were paved, dug up, repaved, and sometimes moved a few meters without consideration of environmental impacts. Despite the lack of definitive knowledge of the cave's original complex pattern of air flow, bulky, ineffective airlocks were installed to supposedly restore its original pattern of circulation. Very expensive gleaming stainless steel railings detracted even more from the cave's own landscapes. (Although seemingly ice-cold to the touch, such stainless steel constructs are a valuable protection for visitors and for troglobites in voluminous, near-virgin caves which are warm enough for visitors to grasp railings for more than a few seconds, for example, Grotta Grande del Viento, Frasassi, Italy). It is doubtful, however, that any troglobites in and around the tour route have survived its century of abuse. But any troglobite survivors surely were hardy enough to also survive use of more .

Concerning "Standards, Dignity, and Prestige"

In terms of Secretary Lane's "standards, dignity and prestige," Oregon Cave is not in the same class with the other caves which are namesakes of their National Park Service unit: Carlsbad Cavern, Mammoth Cave, Wind Cave, Jewel Cave, Timpanogos Caves, and Russell Cave. Locally, Mammoth Cave is more than a little people-worn. But its vastness and its extraordinary historical and archeological values more than compensate for that. Russell Cave is a special case. It was donated to the National Park System to preserve and interpret a nationally significant archeological sequence. Somehow that archeological sequence no longer is exhibited. But its adjacent subterranean wilderness remains virtually intact. And Carlsbad, Wind, Jewel, and Timpanogos simply are matchless.

Oregon Cave retains much of its value as a show cave but it is surpassed in many ways by such state park caves as Alabama's Cathedral Cavern and Montana's Lewis and Clark Cavern (originally Morrison Cave National Monument). Its scenic resources are surpassed by many privately operated show caves (for example, Texas' Caverns of Sonora) and by at least one cave administered by the USDA Forest Service (Blanchard Springs Cave, Arkansas). Important scientific resources (paleontological for example) exist in the small, undeveloped sections of Oregon Cave, but paleontological resources are not high on the National Park Service's list of qualifications for units of its system. When Utah's Crystal Ball Cave was rejected for national monument status (Wykert 1959), the inspection report did not even mention the numerous bones of prehistoric mammals strewn about its floor (Halliday 1965).

Present Assertions About Uniqueness and National Significance of Oregon Cave

Principal current assertions about extraordinary uniqueness and national significance of Oregon Cave seem to center about "six types of rock," supposedly an extraordinary combination in a cave. This represents a basic misunderstanding which apparently dates from the 1980s. This was the time when Congress chose the USDA Forest Service to administer Washington State's new Mount St. Helens National Volcanic Monument including Ape Cave — then the longest lava tube cave on the American continents. To the surprise of many American conservationists, including me, the USDA Forest Service promptly demonstrated that it was capable of administering national monuments quite ably.

Some conservationists, again including me, suspect that this was threatening to administrators of a nearby unit of the National Park System which could not be brought into compliance with standards of the National Park Service.

Even in the 1950s and 1960s, there was evidence of concern about this. In 1959, while serving as Assistant Park Naturalist of Crater Lake National Park (which then administered Oregon Caves National Monument), Richard Brown expressed the hope that I could find something unique and extraordinary about Oregon Cave. The most I could provide was a conclusion that Oregon Cave has all the features of a large cave system in a remarkably small area (Walsh and Halliday 1971 and 1978, Halliday 1977). This conclusion evidently was insufficient; I am unaware that it ever appeared in any National Park Service publication.

The six types of rock cited in the "Official Map and Guide" (National Park Service, 2000, 2002) and trailside exhibits are said to be:
(1) "plutonic igneous,"
(2) "contact metamorphic,"
(3) "regional metamorphic,"
(4) "volcanic igneous,"
(5) "clastic sedimentary,"
(6) "chemical sedimentary."

At the 2005 National Speleological Society Convention I presented this classification to the session on Cave Geology and Geography (Halliday in press). No one spoke to concur with it; one problem is that it conflicts with the long-standing mainstream of geological thought which recognizes only three types of rock: igneous, metamorphic and sedimentary.

Further, documentation of the existence and significance of the "six types of rock" in the cave is tenuous. For example, "volcanic igneous" rock is said to be represented by volcanic ash (a very common component of soils throughout much of the Pacific states). My tour guide in April 2005 was less than convincing about this. Stopping at the trailside patch of supposed volcanic ash (which looks like ordinary cave silt on a ledge), he explained that it had not been confirmed as volcanic ash, "But they're going to examine it soon."

Still further, the principal "plutonic igneous" rock in the cave likely is nothing of the sort. This is the supposed "quartz diorite" dike in the Ghost Room depicted in the "Official Map and Guide" and pointed out by tour guides. In the 1960s, a thin section microscopic study of a sample of this dike by former NSS President George W. Moore revealed that its contents were compatible with a sedimentary dike instead (Moore ca. 1962, cited in Halliday 1963, 1966-67, 1969). At least in the mid and late 1960s, his report was in National Park Service files, and even before this analysis, National Park Service publications referred to it as a clastic dike (for example Anon. 1958, 1959, 1960).

The only metamorphic rock in the cave is the marble in which it formed, with a very small amount of argillite and perhaps of other impurities also present in the block of marble. Neither of these occurrences is unique or extraordinary. Dozens of other caves in the Klamath Mountains and hundreds in the nearby Sierra Nevada also formed in marble with similar small quantities of impurities. In many of them, other metasedimentary, metavolcanic, and igneous rocks can be seen where dissolution of the marble block was especially efficient (Halliday in press). With rare exceptions, (for example Black Chasm, Calif), such noncarbonate rocks are not part of the caves from which they are viewed. The fact that they can be viewed from Oregon Cave is unremarkable; they can be viewed better in road cuts and in other surface exposures.

Listing of both "contact metamorphic" and "regional metamorphic" rock apparently implies that various degrees of metamorphism can be detected within the cave's marble. It is doubtful that this is the case. Any supposed "contact metamorphism" adjacent to the clastic dike would be surprising.

Finally, subdividing Oregon Cave flowstone into either "clastic sedimentary rock" or "chemical sedimentary rock" is not in accord with basic karstic mineralogy (for example Hill and Forti 1997).

During the present symposium, John Roth (oral communication) defended the systematic publication of these and other misstatements (Table 1), saying they were intended "to challenge readers," a practice he attributed to Park advocate Freeman Tilden. It is difficult to believe that Tilden or any other National Park Service spokesman would condone or urge National Park Service publication of false or misleading assertions.

The National Commission on Risk Assessment and Risk Management

It is clear that not all of the Oregon Cave problems we surfaced in 2003 (Halliday and Swofford 2003) can be resolved as long as the cave is administered as part of the National Park System. Our 2003 recommendation that Oregon Caves National Monument be returned to the USDA Forest Service remains valid. In these days of tighter Federal budgets, however, some alternatives also should be considered: transfer of the cave to the Oregon state park system, to Josephine County for a county park, and even privatization. Decisions regarding its disposition should not be hasty, nor should they be "command-and-control" decisions like President Roosevelt's Presidential Proclamation. This implies a (hopefully) short period of continued management of the cave by the National Park Service.

During this interim period, certain recommendations of the National Commission on Risk Assessment and Risk Management seem both appropriate and useful. If these recommendations had been in place at Oregon Cave since 1980, controversies would have been greatly reduced and management of the cave would have been much healthier: healthier for the cave, for its denizens, and for its visitors. This is because all cave management poses at least potential risks, and bad management poses increased risks. Such risks can be minimzed by:

- utilizing all relevant information in decision matrices;
- involving "stakeholders" in a cooperative decision framework;
- employing alternatives to command-and-control decisions, and also employing alternatives to default decisions, to the greatest degree possible;
- utilizing meaningful peer review mechanisms which include stakeholder input, and;
- utilizing iterative management strategies after decisions are made.

All these principles are recommendations of this Commission.

Evolution and Development of the National Commission

Congress initially mandated a narrow role for this commission: to study and make recommendations on health risks from air pollution. However its role was expanded by both the first Bush administration and the Clinton administration. It eventually encompassed other health risks and risks to the environment. When it was completing its work in 1997, its members realized that they also had gone beyond the original intention: that its recommendations be directed toward federal programs. Its framework thus evolved into broad principles also applicable to "public and private entities at the state, regional, and local levels" (Presidential/Congressional Commission 1997). Its two-volume final report is readily accessible on the Web by searching for "Commission on Risk Assessment." Because of its ultimate breadth, some 60% of this report is irrelevant to cave management (risks from drugs, risks from chemicals, risks from irradiation, and so on). Cave managers will find the other 40% provocative and generally applicable in a wide variety of decision and management matrices.

The commission's report began with six broad, seemingly oversimplified principles:
(1) defining each problem and putting them into context,
(2) analyzing the risks associated with each problem,
(3) examining the options for addressing each risk,
(4) making decisions about which options to implement,
(5) taking actions to implement these decisions,
(6) evaluating the results of each action.

It immediately went on to specific new ground, however, stressing that this framework must be conducted in collaboration with "stakeholders," (persons and entities potentially affected by such decisions). Further, because decisions often must be made on the basis of incomplete information, management plans must be subject to change ("iteration") as new information becomes available. It did not use the word "stonewalling," but its criticism of this traditional practice is clear. It repeatedly condemned "default decisions," perhaps an equally traditional practice.

Additional new areas included its recommendation of avoidance of command-and-control decisions "whenever possible," and its recommendation of independent peer review of pending decisions, with stakeholders included on the peer review panel. Perhaps most controversial, it urged that the entire process be open to the public and the media, with "honesty and accuracy," and that the weight of evidence supporting different assumptions and conclusions be laid out for all to review.

While some of the management problems at Oregon Cave are beyond the reach of these principles (for example its geometry), even cursory consideration indicates that many current Oregon Cave controversies exist because its administrators did not comply with these recommendations. Further, it is not difficult to think of other cave management controversies in which they would have been very helpful: administration of Mammoth Cave National Park at the time of the C-3 Expedition (resolved eventually); administration of the Gifford Pinchot National Forest before, during, and after the initial eruptions of Mount St. Helens 1980–1981 (soon resolved); the secret 1990 gating of Mowich Cave, Oregon, by the Umpqua National Forest (recently resolved); 15 years of cave management controversies at Hawaii Volcanoes National Park culminating with the unjustifiable 2005 closure of its Kilauea Caldera caves cased by unsupported speculation about possible dangers from CO_2 (unresolved).

These new Federal standards are binding on no one and no agency — not even the Environmental Protection Agency which was heavily involved in their development. But they now provide cave managers an unparalleled mechanism for risk management and conflict resolution. The National Speleological Society should recommend their implementation as widely as possible.

Table 1. Some other misstatements in the 2002 "Official Map and Guide" of Oregon Caves National Monument.

1. "Cavers use (cave) popcorn as a compass to find new passages or, when lost, their way out."	During this symposium, John Roth defended this statment to me, face-to-face, stating that it was based on his personal experiences. Since coralloids ("cave popcorn") are found over a vertical range of about 1,000 feet in Carlsbad Cavern, I suggested that he present his findings at the 2006 N.S.S. Convention session on cave geology and geography. He demurred.
2. The drawing of the supposed Pacific giant salamander actually is that of a common eastern spotted salamander (probably *Ensatin*a sp). 	During this symposium, John Roth defended this attribution to me, face-to-face, on the basis of species variability cited in taxonomic texts. I suggested that he present this attribution at the 2006 N.S.S. Convention session on cave biology. He demurred. 
3. The cutaway diagram portrays an imaginary scene of great scenic impact (as well as supposed examples of the "six types of rocks").	No vista in the cave has so great a scenic impact.
4. (The Pacific giant salamander is) "one of the few amphibians known to vocalize."	Anyone who has been in a tropical rain forest at night is likely to doubt this statement.
5. "A salamander warns us of changes in our environment."	This is imagination run wild.
6. "Since 1985 … crystal clear water once again cascades over white marble."	This implies that only the post-1985 NPS operations in Oregon Cave produced this result. This is outright fabrication. I observed "crystal-clear water cascading over white marble" in the cave in 1948, 1959, 1960 and other dates before 1985.

7. "Since 1985 … new lighting and trail system will reduce evaporation and unnatural foods. "	Evaporation varies naturally in different parts of the cave. This is largely imagination and speculation. And just what are "unnatural foods," anyway?
8. "Since 1985 … one can now see a renewed cave."	This is simply untrue. The tour route is cleaner than in 1985, but many of the cleaned speleothems are now mud-colored and the route still is a gutted husk, even more cluttered with air locks and stainless steel railings than before 1985. Further, there is no documentation that any biota of the tour route is "renewed."
9. The cave is "lighted with an improved trail."	In April 2005 three short sections of the tour route were in total darkness so that our party had to grope our way along the wall. One of these dramatic sections included two rock steps.
10. "Cave temperatures are around 40° F year-round."	In April 2005, the entrance passage was below freezing with icicles which were dry to the touch. I observed the same thing in 1959, 1960, and 1961.
11. "Surface trails are not maintained during snow conditions" but it is implied that it is safe to visit the cave at such times.	In April 2005, compact snow and ice on the exit trails created very dangerous conditions.
12. The leaflet notes that "several passages are narrow with low ceilings" but adds: "do not touch or lean on the cave walls or formations."	Even where well-lighted (see above), in narrow passages with low ceilings touching the walls, ceiling, and formations is unavoidable.
13. "Airlocks have restored natural cave winds by blocking air flow in artificial tunnels."	During this symposium, John Roth acknowledged to me that the airlocks had been unsuccessful in doing this.
14. "Oregon Cave...is rich in diversity". " … one of the world's most diverse realms … ," "The surface world of Oregon Caves mirrors the diversity found underground." and so on.	This is mere puffery. There is no valid reason to speculate that that the environment of Oregon Cave is any more diverse than that of numerous other caves at various elevations in the Klamath Mountains (Halliday and Collier, 2005).
15. The "Official Map and Guide" repeatedly refers to "cave ghosts."	This is not a recognized term in geology nor cave mineralogy (for example, Jackson, editor 1997; Hill and Forti 1997).

16. Moonmilk "is created by the same type of bacteria used to make today's antibiotics."	The April 2005 tour guide translated this as "Moonmilk is as good as an antibiotic ointment." which also is untrue. Most of today's antibiotics are synthetic, and bacteria used to create others are from strains which are selected and purified with extreme care, not those which make moonmilk in caves.
17. The supposed "pallid bat" depicted in the leaflet actually is a free-tailed bat, presumably *Tadarida mexicana*. Also, "healthy numbers" of pallid bats are said to be present in the cave now.	Note: It is doubtful that any pallid bat ever has been found in Oregon Cave.
18. The leaflet implies that its four photos of cave minerals were photographed in Oregon Cave.	Probably none of these photos were taken in Oregon Cave. The photo of cave pearls probably was taken in Carlsbad Caverns.
19. "A myriad of calcite formations decorate the cave."	Most of the tour route lacks speleothems.
20. "Note the keyhole-like shape of the cave formed by the roundish chamber and the notch caused by the downcutting of the stream."	This sentence is largely imagination. In only a little of the cave is its cross-section keyhole-shaped.
21. The paragraph and block diagrams on subduction are confused beyond recognition.	When I presented the block diagrams to the 2005 NSS Convention session on cave geology and geography, no one in the audience could comprehend the meanings of the diagrams. My tour guide in April 2005 gave a concise, clear explanation of subduction without referring to the leaflet.
22. The spotted owl is said to be the chief predator of flying squirrels.	Spotted owls don't even occur in some 99% of the ranges of flying squirrels in the USA .
23. Oregon Cave is "nestled within an unusually diverse array of rock types."	Oregon Cave is nestled entirely within marble. And non-carbonate rocks outside its marble block are similar to those in many other speleoliferous sections of the Klamath Mountains and Sierra Nevada (Halliday and Collier 2005).

24. "Violent geological events spanning millions of years have created (Oregon Cave)."	No violent geological events were involved in the creation of Oregon Cave — only ordinary dissolution of marble. As for "millions of years," this is spin. Steve Turgeon's studies (for example Turgeon and Lundberg, 2001) show no evidence of speleothem deposition much before 500,000 years before present. The date of conversion from a closed to an open system is uncertain and probably different in different parts of the cave. Inception of Oregon Cave passages obviously began earlier than speleothem deposition, but at present, it is unjustified speculation to assign a specific date to its dissolution processes, much less a sensational date of "millions of years."

Table 2. Some additional misstatements by my tour guide, April 2005

1. Cave popcorn (coralloids) is/are known as "compass rock."	
2. Cave popcorn (coralloids) always point(s) toward a cave's entrance.	
3. "Moonmilk is as good as an antibiotic ointment."	
4. "Calcite is white because it contains air bubbles.	Evidently he has never seen Iceland spar.
5. Caves in marble are very special.	He didn't say why they are special, or where. They are ubiquitous in the Klamath Mountains and Sierra Nevada.
6. "Grizzly bear bones more than 50,000 years old have been found in the cave."	Grizzly bears probably had not yet differentiated from *Ursus arctos* 50,000 years ago.

7. Virtually all destruction of cave features occurred before National Park Service management of Oregon Cave.	During this symposium, John Roth defended this statement to me, face-to-face. He insisted that the Monument files contain photo documentation of this. Jay Swofford is equally insistent that Friends of Oregon Caves files contain photo documentation of extensive destruction of cave features during the 70 years of National Park Service management. See Halliday and Swofford, 2003.
8. The guide used the term "stalagtite" repeatedly.	
9. The guide misled the tour group about the old trail in the cave. He pointed out its narrowness in the Wigwam without mentioning that its historic iron railing had been removed recently.	This historic iron railing evidently was removed without compliance with Federal law on historic features. Also, its removal renders unsafe any use of the old trail during emergencies or for other reasons (for example photo documentation).

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THE NATIONAL PARK SERVICE'S CAVE AND KARST MANAGEMENT PROGRAM

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Abstract

Considerable cave exploration, restoration, research, and other speleological activities are conducted within parks. Although the National Park Service occasionally can accomplish small projects with its own employees, most of the work is accomplished by individuals and groups interested in increasing scientific knowledge of cave and karst systems. Such groups and individuals contribute the majority of cave and karst research and projects. Currently the National Park Service has national level agreements with the Cave Research Foundation, the National Speleological Society, and Bat Conservation International. Speleological projects and research are also coordinated through individuals associated with these groups as well as the Geological Society of America, the American Geological Institute, the U.S. Geological Survey, and the Karst Waters Institute. Without such partnerships, only a small fraction of projects and research conducted in caves and karst could be accomplished.

The various units administered by the National Park Service are a shared dream for all Americans and, by extrapolation, for all peoples of the world for all time. Without the continued involvement of volunteer groups we would not be able to implement a cave and karst program that will provide for the protection of natural processes in cave ecosystems; understand karst landscapes; conduct scientific studies about cave and karst resources; increase the Service's scientific knowledge and broaden the understanding of its cave resources; and provide accurate educational opportunities for a broad spectrum of park visitors to safely visit, study, and enjoy caves; and continue to ensure the sustainable use conservation, interpretation, and protection of cave and karst resources.

FACILITATING RESEARCH AT CARLSBAD CAVERNS NATIONAL PARK

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Abstract

As a federal agency that manages millions of acres of public lands, the National Park Service has a fundamental purpose to conserve park resources and values while providing for the enjoyment of the people. Management of park resources has, in recent years, been more oriented towards making good, sound decisions based on valid scientific research. This presentation will discuss actions taken by Carlsbad Caverns National Park staff to promote and facilitate research in the park.

SOURCE AREA DELINEATION OF RUSSELL CAVE NATIONAL MONUMENT AND CHICKAMAUGA AND CHATTANOOGA NATIONAL MILITARY PARKS

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Abstract

In an effort to better understand groundwater flow under two of its national parks, the National Park Service gave a grant to the Center for Cave and Karst Studies to conduct a source-area delineation for Lookout Mountain National Military Park and Russell Cave National Monument. Both sites have similar karst landscapes and geologic stratigraphy. Lookout Mountain is a synclinal mountain that lies within the Folded Appalachians. Its stratigraphy mimics that of the near-by Cumberland Plateau. The caves tend to be oriented along the strike and there are numerous vertical shafts where cave streams drop off resistant stratigraphic layers. Russell Cave National Monument lies within Doran Cove, Alabama and Tennessee, and has near-horizontal structure and Cumberland Plateau stratigraphy. Cave streams drop off the same resistant stratigraphic layers and tend to flow through caves that follow stress-relief fractures that parallel the valley walls.

Dye tracer tests in the vicinity of Russell Cave showed that the watershed for Russell Cave encompasses all of Doran Cove. Tracer tests atop Lookout Mountain indicate that cave streams are trapped by the synclinal structure of Lookout Mountain and flow along the strike. The cave streams take a stair-step pattern as they breach confining layers and descend through the Pennington, Bangor, and Monteagle Limestones. This hydrogeologic research has identified the major flow routes of the karst aquifers under Lookout Mountain and Doran Cove, and has also delimited the drainage basins (source areas) for the major cave streams and springs.

Continuing research is being funded by the National Park Service and the Center for Cave and Karst Studies.

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