



# Proceedings for Conservation of Fragile Karst Resources

A Workshop on Sustainability and Community in support of  
UNESCO science programs

August 18-20, 2020



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**Front Cover:** Passage photos by Alan Cressler  
Cave biology by Rick Olson

**Back Cover:** Entry sign in Mammoth Cave National Park  
photo by P. Kambesis

**Karst 2020**

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## Welcome to KARST 2020 AUGUST 18-20, 2020

Western Kentucky University, the George Wright Society, and the Mammoth Cave Area Biosphere Reserve present the **Conservation of Fragile Karst Resources: A Virtual Workshop on Sustainability and Community**. The purpose of this meeting was to enhance communication and the sharing of ideas and resources between major international conservation and science programs that protect, study, or manage cave and karst resources. The meeting brought together a diverse group of managers, scientists, educators, and community partners to share successes and challenges in promoting sustainability and community involvement while protecting fragile karst ecosystems. The major international conservation and science programs represented included:

- Man and the Biosphere (MAB) <https://en.unesco.org/mab>
- Global Geopark Network (GGN) <http://www.globalgeopark.org/>
- International Geographical Union Karst Commission (IGU KC) <https://sites.google.com/site/igukarstcommission/>
- UNESCO/IUGS International Geoscience Program Project #661 (IGCP) <http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/international-geoscience-programme/igcp-projects/hydrogeology/project-661-new-2017/>
- World Heritage Convention (WHC) <http://whc.unesco.org/en/convention/>
- IUCN Cave and Karst Working Group <https://www.iucn.org/commissions/world-commission-protected-areas/our-work/geoheritage/caves-and-karst>
- International Association of Hydrogeologists Karst Commission (IAH KC) <https://karst.iah.org/>
- World Karst Aquifer Map (WOKAM) Program <https://www.un-igrac.org/resource/world-karst-aquifer-map-wokam>
- International Union for Conservation of Nature (IUCN) <https://www.iucn.org/>
- International Research Center on Karst under the auspices of UNESCO (IRCK) <http://www.irck.edu.cn/irck/>

### Sponsors



George Wright Society  
Crawford Hydrology Laboratory  
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International Geographic Union (IGU)  
Kentucky Geological Survey (KGS)  
International Association of Hydrogeologists (IAH)  
International Union of Speleology (UIS)  
National Cave and Karst Research Institute (NCKRI)  
National Speleological Society (NSS)  
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## Plenary Session



Tuesday, August 18, 2020

### 8:00-9:30 AM (CDT)

- 8:00 Welcome and Opening Remarks  
8:30 Special Message from George Veni, UIS President 2021 International Year of Caves and Karst  
8:45 Stronger Together: A Global Conversation (Panel discussion)

We opened our meeting with the panel discussion *Stronger Together: A Global Conversation*. While people throughout the world may share common goals and desires in their efforts to protect the natural world, in practice these efforts are surely informed by a range of cultural, political, economic, and other influences. In an open-ended discussion, we brought together a diverse group of panelists with a wide range of international experience in conservation, bio-diversity and ecosystem protection to share their perspectives on these ideas

Moderator: Margaret Gripshover, Professor of Geography, Western Kentucky University, USA

### Panelists:

- Sarah Gaines University of Rhode Island, US Advisory Group on Geoheritage and Geoparks; USA  
John Gunn Chair of the International Union for Conservation of Nature's (IUCN) Cave and Karst Working Group; UK  
Eko Haryono Faculty of Geography and Coordinator of the Karst Research Group, Universitas Gadjah Mada; Indonesia  
Aleksandra Maran Natural History Museum in Belgrade, Commission for the Geoheritage Conservation, Serbian Geological Society; Serbia  
Tom Gilbert Retired from the US National Park Service and UNESCO Man and the Biosphere Program, USA

### 9:45 - 11:30 Plenary Session: Sustainability and Community

- 9:45 Bolger, Terry Collaborative Management with Local Communities for the Conservation of Karst resources at Him Nam No National Park, Laos  
10:00 Gunn, John How Well is Cave and Karst Geoheritage Protected by UNESCO Protected Area Designation?  
10:15 Telbisz, Tamás Karstic National Parks' Roles and Potentials – Views and Opinions from Tara National Park, Serbia  
10:45 Fakin Bajec, Jasna Landscape Perception and Traditional Knowledge for Sustainable Development of UNESCO Skocjan Caves Area, Slovenia  
10:30 Imecs, Zoltán Karst Management in Apuseni Nature Park, Romania  
11:00 Younes Arrad, Taha Moroccan Caves and Their Implications for Scientific, Geoeducational and Geotouristic Programs through Speleological Activities

## Technical Sessions (Concurrent)



Tuesday, August 18, 2020

### Conservation Tools 11:45 AM – 13:45 PM (CDT)

11:45	Shackelford, Jennifer	Virtual Field Trips to Your Park-An Inexpensive Way to Reach the Masses
12:00	Hildreth-Werker, Val	Cave Conservation and Restoration: Workshops Around the Globe
12:15	Webb, Cathleen	The 2020 Mammoth Cave Natural Resource Condition Assessment
12:30	Holliday, Cory	Forest Management Considerations and Best Management Practices on Karst Landscapes: A Lesson in Evidence-Based Management Guidelines
12:45	Carlson, Justin	Middle to late Holocene Soil Geomorphological History at Crumps Cave and Sink, Potential Implications for Soil Conservation and Karst Terrains Today
13:00	White, William	A Blueprint for the Assessment of Inorganic Carbon Flow Paths in the Great Onyx Groundwater Basin, Mammoth Cave National Park
13:15	Meyer, Sonia	How Visitation is Affecting Air Quality in Carlsbad Cavern
13:30	Addesso, Rosangela	Lampenflora, the Alien of Show Caves: Monitoring and Treatments

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### Conservation Science 11:45 AM – 13:45 PM (CDT)

11:45	Ćalić, Jelena	Stripe Karst Tectonic Settings – Examples from Eastern Serbia
12:00	Olarinoye, Tunde A	New Approach for Automatic Extraction of Karst Conduit and Matrix Recession Coefficients
12:15	Ford, Derek	Mahony and Tunago, Adjoining but Contrasted Karst Plateaus in the NT, Canada
12:30	Fryar, Alan	Variable Responses of Mountainous Karst Springs to Seasonal Precipitation
12:45	Chamba, Bryan	The First Electrical Resistivity Tomography Study Applied to an Ecuadorian Cave (Uctu Iji Changa, Tena): Insights into Amazonian Karst Systems
13:00	Fandel, Chloe	Representing Uncertainty with Diverse Model Ensembles: A Test Case in an Alpine Karst System
13:15	Rasnake, Lindsey	Characterizing Perennial Bedrock Springs in the Low-Yield Aquifer Region of Southwest-Central Indiana
13:30	Ponta, Gheorghe	Monitoring Karst Aquifers in North Alabama for the Protection of Sensitive Aquatic Biota

## Poster/Flash-talk Session

**Wednesday, August 19, 2020**

This session was a combination of poster presentation and flash-talks.



### **8:00-9:40 AM (CDT)**

- |      |                       |   |
|------|-----------------------|---|
| 8:00 | Gabrovsek, Franci     | Environmental Monitoring in Škocjan Caves, Slovenia   |
| 8:10 | Serena Liso, Isabella | Complexity and Fragility of Apulian Groundwater Resources   |
| 8:20 | Parise, Mario         | Establishing a Geopark in the Alta Murgia (Italy)   |
| 8:30 | Ruggieri, Rosario     | Clean up the Dark: Karst and Cave Conservation Initiative of the Italian Speleological Society (SSI)  |
| 8:40 | Zorman, Tomaz         | Škocjan Cave – The Cave and the Paths of its Explorers. Reflection of Speleology in Classical Karst through Documentary Movie and Presentation (FILM) |
| 8:50 | Van Beynen, Philip    | The Economic Value of Florida's Groundwater   |
| 9:00 | Gani, Nahid           | Investigating Geologic Controls of Western Pennyroyal Karst Region, Kentucky  |
| 9:10 | Williams, Jessica     | In-cave Tracing to Measure Discharge in the Great Onyx Flow System, Mammoth Cave National Park, Kentucky  |
| 9:20 | Gessert, Alena        | Geotourism and Local Development in NP Slovak Karst: Behaviour Survey of Local People, Tourists and Experts   |

# Virtual Field Excursions

Wednesday, August 19, 2020

Though virtual tours cannot replace the physical experience of visiting Mammoth Cave National Park and the Mammoth Cave Area Biosphere Reserve, our field trip leaders presented tour highlights, discussed related topics, and answered questions.



**10:00-11:00 AM CDT**

**Karst Hydrogeology of Mammoth Cave National Park: Why is the World’s Longest Known Cave Here?** Mammoth Cave National Park forms the core area of one of the world’s iconic karst landscape/aquifer systems also designated as a UNESCO Biosphere Reserve and World Heritage Site. Mammoth Cave itself has a known length of more than 660 km, with more explored and mapped continuously, and at least another 305 km of mapped passages lie nearby. This virtual classic field excursion explored the surface and subsurface landscapes of the Pennyroyal and Mammoth Cave Plateaus with a focus on understanding the geologic and climatic elements that have conspired to form the “perfect storm” of karst development that we see here. We also discussed work of the pioneers of karst science who have been drawn here over the years. **Leaders:** Dr. Will White, Professor Emeritus, The Pennsylvania State University, Dr. Art Palmer, Professor Emeritus, State University of New York at Oneonta, and Dr. Chris Groves, University Distinguished Professor of Hydrogeology, Western Kentucky University .

**Archaeology and Cultural Resource Management at Mammoth Cave.** This trip 'took place' in the Historic Section and Lantern Tour Route of Mammoth Cave. Highlights from the historic era include remains of the 1812 saltpeter mining industry, structural remains from the experiment to cure consumption (tuberculosis) patients in the 1840s, and Gothic Ave. signature hall dating to the early 1800s. Highlights from Native American use of the cave include evidence for the mining of gypsum and other minerals, abundant perishable remains from this activity, and petroglyphs and pictographs. All of this activity dates between 3000 and 2000 years ago. **Leaders:** Dr. George Crothers, Associate Professor and State Archaeologist, University of Kentucky, and Ed Jakaitis, Cultural Resource Manager, Mammoth Cave National Park.

**11:30-12:30 AM CDT**

**Urban Karst Challenges: A Remediation Success Story.** This trip focused on urban and industrial impacts to Hidden River Cave and what has been called “the greatest cave restoration success story in the United States.” Learn about how the American Cave Conservation Association played an integral role in changing a ‘domestic and industrial sewer’ back into a healthy cave ecosystem and show cave now visited by thousands of tourists and students each year. **Leader:** Dr. Pat Kambesis, Chair International Projects, Cave Research Foundation; Instructor of Geography/GIS, Western Kentucky University

**Mammoth Cave Ecology.** Park specialists and participants explored the ecological aspects of surface and subsurface locations in Mammoth Cave National Park. The trip focused on the interconnected nature of surface and subsurface ecosystems in a karst landscape, resource protection issues, and long-term monitoring strategies being implemented at Mammoth Cave National Park. Examples discussed included regional and local human influences, processes linking surface and subsurface ecosystems, known subsurface communities, and potential vital signs. **Leaders:** Kurt Helf, Ecologist, Cumberland Piedmont Network, Rick Olson, Ecologist, Mammoth Cave National Park, and Rick Toomey, Cave Resource Management Specialist, Mammoth Cave National Park

## Workshops

Thematic workshops facilitate collaboration between international resource protection programs and to inform karst conservation, sustainable development, and community involvement efforts in the world's premier karst regions. Workshops are 1.5-hour blocks of time that were organized to achieve a specific outcome.



### **SESSION 1 – Thursday, August 20, 8:00-9:30 AM (CDT)**

#### **Exploring Best Practices in Data Management, Integration, and Visualization.**

Facilitators: Sarah Arpin, Geologist II, Kentucky Geological Survey, and Dr. Pat Kambesis, Center for Human Geoenvironmental Studies, Department of Earth Environment and Atmospheric Sciences, WKU

This workshop intended to help resource managers and researchers consider data from a data-management perspective. An important focus was exploring tools and techniques for getting the most value out of data. A holistic approach to storing, accessing, and processing data is key to better understanding, management, and protection of vulnerable resources, environments, and ecosystems. The integration of data of all types, sources, and formats for a unified view was also covered. Visualization of data beyond tables and graphs, using creative 2-D, 3-D, and spatial maps and models, was explored. Limitations of various software programs used to access, manage, manipulate, and visualize data were considered. Participants engaged in open discussion of current practices in data management, integration, and visualization, learned from peers, and received instruction on emerging techniques. Both professionals and the public can benefit from community involvement through crowd sourcing data and citizen science. Making data available through an easy-to-use interface for visualization, searching, and reusability is key to understanding and protecting our natural resources.

#### **Significance of Cultural Heritage in Karst Landscape Management: 2030 Agenda for Sustainable Development**

Facilitators: Darja Kranjc, Higher Nature Protection Counselor, Skocjan Caves Park, Slovenia, and Jasna Fakin Bajec, Institute for Culture and Memory Studies, Research Centers of the Slovenian Academy of Sciences and Art

This workshop defined cultural heritage and explained potential differences with what is understood as cultural resources and cultural values. After an up-to-date theoretical explanation, practice examples were shared on how cultural heritage typical for limestone areas can help towards achieving the Sustainable Development Goals (SDGs), elaborating on the reasons for and practical usage of cultural heritage in management of the UNESCO Karst and Reka River Basin Biosphere Reserve (Slovenia). Participants were invited to produce a draft of their own “Karst Cultural Heritage Database”, co-create a template for proper sustainable solution development based on cultural heritage, and discuss creation of an open database of sustainable traditional practices and solutions on karst areas around the globe.

#### **Gazing Deeply: The Art and Science of Mammoth Cave.**

Facilitators: Dr. Chris Groves, University Distinguished Professor of Hydrogeology, Western Kentucky University and Tiffany Isslehardt, Curator and Development Manager, Kentucky Museum,

This tour featured the *Gazing Deeply* exhibition, a collaborative effort between Mammoth Cave National Park and Western Kentucky University arts and science faculty and students that highlights one of the most well-known and vital karst landscapes in the world.

### **SESSION 2 – Thursday, August 20, 10:00-11:30 AM (CDT)**

#### **Citizen Science, Research and Land Management in Karst**

Facilitator: Ben Tobin, Karst Hydrogeologist, Kentucky Geological Survey

Cavers have long been integral to understanding and protecting cave resources around the world. This workshop brought together cavers, scientists, and managers to discuss the history of these interactions, ways each group has helped the other, challenges to improving our understanding of cave resources and management, and a path for-

ward in continuing to build these relationships.

### **CaveMAB**

Facilitators: Clayton Lino, Speleologist, Coordinator, Mata Atlantica Biosphere Reserve, Brazil and Lee Anne Bledsoe, Research Hydrologist, Assistant Director, Crawford Hydrology Laboratory at WKU

The CaveMAB network (<https://cavemab.com/>) is an informal thematic network within the UNESCO Man and the Biosphere (MAB) program. CaveMAB was recently formed in 2018 and hopes to connect people from the more than 100 biosphere reserves with cave and/or karst resources across the globe. The network is multidisciplinary and plans to address the similar challenges we all face, whether social, educational, cultural, or scientific, in protecting the biodiversity of the unique cave and karst environments within Biosphere Reserves (BR). The goal of this workshop was to reach alignment around shared values and vision for the CaveMAB network and choose an activity to celebrate the International Year of Caves and Karst 2021 and MAB's 50th Anniversary. Anyone working in a cave or karst BR, whether it be via direct BR management or through partner agencies, is encouraged to attend.

### **Teaching Karst Through Environmental Education**

Facilitators: Jennifer Shackelford, Education Specialist, Mammoth Cave National Park and Jeanine Huss, Professor, School of Teacher Education, WKU

Teaching the youth of the world about karst areas is very important. We want to encourage people to make good choices with our environment, so caves and groundwater are not negatively impacted. By teaching youth about caves and karst we are making a positive long term investment in the future of our karst regions. This workshop presented various ways to teach about cave and karst areas to different age groups and allowed participants to discuss challenges encountered within their own programs and collectively brainstorm solutions. Anyone interested in educational karst programming was encouraged to attend. Participants left the session with examples of 4th and 5th grade educational programming from Mammoth Cave National Park and links to kindergarten through middle school curriculum.

### **Tools and Techniques for Urban Karst Hydrology and Hazard Monitoring and Management**

**Leaders:** Dr. Jason S. Polk and Adam Shelley, Center for Human Geoenvironmental Studies, Department of Earth Environment and Atmospheric Sciences, WKU

Participants took part in a virtual experience to visit several sites and engaged in case studies involving various methods and techniques for data collection, monitoring, and equipment/instrumentation use in conducting research and/or collecting data in urban karst systems. Covered topics included emergency management planning for groundwater and hazard mitigation (sinkholes, contamination events, long-term monitoring, etc.). This involved an overview of setting up a sampling or monitoring site, monitoring techniques, analytical techniques, data logger deployment and utilization, software selection and usage, data processing, and other related topics. The workshop topics included the current status of urban karst groundwater monitoring and future directions for planning for high-resolution monitoring, groundwater quality monitoring, hydrologic and geochemical monitoring, flood and hazard monitoring, study site security, and others. It also included a case study of integrating these techniques in the National Corvette Museum sinkhole project and the elements of its formation, impacts, and remediation. This highlights the importance of collaborative karst hydrologic and geotechnical investigations to better understand and remediate karst hazards and the usefulness of combining existing and new methods during the process, along with education and outreach, to build resilience against these urban karst hazards through improved awareness and implementation of advanced techniques.

## Abstracts

### Geochemistry

#### Variable Responses of Mountainous Karst Springs to Seasonal Precipitation

Alan Fryar, University of Kentucky, Lexington, Kentucky USA, Joshua Barna, ARM Group, Brett Howell, AECOM

Responses of karst springs to precipitation depend on climate, geologic structure, lithology, land use/land cover, and relief. We contrast the responses of springs in two mountainous, subtropical regions with pronounced wet/dry seasons and similar total annual precipitation (~1100–1300 mm). In the Middle Atlas of Morocco, Zerouka spring is located at ~1616 m asl on a dolomitic limestone plateau. The climate is Mediterranean (dry summers) and the landscape is a forest-rangeland mix. During continuous monitoring from March 2014 to May 2015, water temperature (T) was relatively constant and stage showed a broad minimum in late summer. Stable isotopes of water (deuterium and oxygen-18) fluctuated daily but were typically out of phase with each other except in late winter–early spring. In Guizhou province, China, Maoshuikeng spring is located at ~1212 m asl and drains a cockpit karst basin developed in limestone and dolomite. The climate is monsoonal, with ~80% of precipitation falling from May to October, and land use is marked by small farms and villages. We monitored water T, stage, and chemistry for 46 hours following a June 2018 storm. Minimum water T occurred ~24 hours after the stage peak, while deuterium and oxygen-18 co-varied, appearing to show three pulses of recharge, as indicated by successive drops and rebounds. We attribute differences in the behaviors of these two springs to the lower intensity of storms and the lesser extent of carbonate weathering in the Middle Atlas.

#### Characterizing Perennial Bedrock Springs in the Low-Yield Aquifer Region of Southwest-Central Indiana

Lindsey Rasnake, Lee Florea, Stephanie LeGare, Indiana University, Indiana Geological and Water Survey, Bloomington, Indiana USA

The extensive karst aquifers of southwest-central Indiana are characterized by springs where emergent groundwater has been an important resource for rural communities for drinking water, agriculture, and commercial uses. Historical surveys of select karst springs have provided flow measurements and geochemistry data, but have not focused on the geospatial variations between physiographic regions, underlying geology, or

changes in spring chemistry over time that may be related to changes in land use or climate. In collaboration with the Center for Rural Engagement at Indiana University, we are characterizing 100 springs and aiming to combine historical data with new data to create a baseline of water quantity and quality that reflects spatial changes across 10 counties in southwest-central Indiana. In our first field season we sampled from 30 springs in Monroe and Greene counties. Field measurements include basic water-quality parameters and discharge. From collected samples, we are measuring E. coli, nutrients (nitrate, nitrite, ammonia, ortho-phosphate), principal ions (including sulfate and total alkalinity), and trace metals. Additionally, we will analyze the suite of samples for stable isotopes of hydrogen, oxygen, and dissolved inorganic carbon. For those sites having elevated total dissolved solids (e.g., mineral springs), we will also measure the stable isotopes of sulfur to evaluate water-rock interaction pathways and their influence on water type and aquifer quality. Baseline data will be used to build a publicly accessible geospatial database, fostering community engagement, awareness, and conservation around these important groundwater sources.

### Geology

#### Stripe Karst Tectonic Settings-Examples from Eastern Serbia

Jelena Calic<sup>1</sup>, Ana Mladenović<sup>2</sup>, Aleksandar S. Petrović<sup>3</sup>, and Vojkan Gajović<sup>4</sup>  
<sup>1</sup>Geographical Institute Jovan Cvijić, Serbian Academy of Sciences and Arts 9 Djure Jaksica, Belgrade, Serbia 11000;  
<sup>2</sup>Faculty of Mining and Geology, University of Belgrade, Serbia; <sup>3</sup>Faculty of Geography, University of Belgrade, Serbia; <sup>4</sup>University of Nova Gorica, Slovenia

The term stripe karst was first described in Scandinavia and denotes km-scale spans of narrow karst belts protruding to the surface along with other lithologies. However, similar karst phenomena are present in some other karst regions as well, although not yet studied to the same extent. A number of stripe karst belts are present in the Carpatho-Balkanides of eastern Serbia, the area which generally abounds with all varieties of contact karst features. Three typical locations are studied in this paper – Dževrinska Greda karst in the Iron Gates area (the Danube River gorge), Krš Mt. karst in the central part of the study area, and Kamenica karst on Stara Planina Mt, further to the south-east. In all these case-studies, the main stripe karst conditions are met, such as overlapping of allogenic

impacts on karst from both sides of a stripe, but there are other characteristic details which enable classifications to various types. Tectonic setting of the studied areas holds the crucial significance in understanding the morphogenesis of each particular stripe, so it is studied in detail, using both remote sensing and field mapping. All the studied karst stripes host extensive caves, which enabled the underground structural-geological mapping as well. All the results are interpreted also on the regional scale and contribute to the general understanding of Carpathian-Balkan transition zone.

**The First Electrical Resistivity Tomography Study Applied to an Ecuadorian Cave (Uctu Iji Changa, Tena): Insights into Amazonian Karst Systems**

*Bryan Chamba<sup>1</sup>, Evelyn Garcia<sup>1</sup>, Celine Mandon<sup>1</sup>, and Elisa Piispa<sup>1</sup>*

*<sup>1</sup>School of Earth Sciences, Energy, and Environment, Yachay Tech, Carlos Mantilla Jose Andrade, Quito Pichincha 170201, Ecuador*

The presence of carbonate rocks and high levels of precipitation have led to the ubiquitous formation of karstic caves in the Napo region of Amazon in eastern Ecuador. Caves such as these represent an important scientific target as they are typically well-suited for paleontological, geophysical, geochemical, and paleoclimate studies. Previous works have shown that resistivity surveys are a very efficient and appropriate way to detect and define shallow caves. However, no studies of this type have been conducted on Ecuadorian caves. Here, we present the first study of this kind from Ecuador. We show the results of applying the electrical resistivity tomography (ERT) technique to characterize the cave Uctu Iji Changa in Napo, Tena, Ecuador. The ERT study was corroborated by speleological inspection of the cave to verify the results from the geophysical surveys. ERT allowed us to determine the location, general geometry, and extent of the cave. In all survey lines, the resistivity contrast between the air-filled voids of the cave and the bedrock is high enough to define the shape and size of the cavity. To know the geomorphology of the cave will allow a better land-use planning to prevent karst resources from being exhausted in developing regions. The research promotes public awareness of the importance of karsts and the threats facing them. Our results demonstrate the efficacy of the ERT technique for detection of shallow caves associated with karstic processes.

**Middle to Late Holocene Soil Geomorphological History at Crumps Cave and Sink and Potential Implications for Soil Conservation in Karst Terrains Today**

*Justin Carlson, Project Director, Kentucky Archaeological*

*Survey, Department of Folk Studies and Anthropology, Western Kentucky University, Bowling Green, Kentucky USA*

Geoarchaeological studies that document long-term soil geomorphological histories of karst landforms in association with paleoenvironmental and archaeological data provide perspective that may be informative for addressing current soil erosion issues in karst terrains. Crumps Cave and Sink are located in the Sinkhole Plain and within the Mammoth Cave Area Biosphere Reserve. Archaeological excavations at Crumps Sink revealed stratified deposits spanning 7200 years ago to present. Magnetic susceptibility, loss-on-ignition, and soil micro-morphological analyses were conducted to examine landform dynamics in response to environmental change and human activities. Between 7200 and 5600 years ago sedimentation was consistent likely due to climatic conditions of the Middle Holocene Thermal Maximum. More pronounced episodes of soil formation between 5600 and 3900 years ago may signal shifting climatic regimes between the Middle and Late Holocene. Enhanced sedimentation occurred between 3900 and 3000 years ago, contemporaneous with increased Native American use of fire for forest clearance and Big Barrens grassland expansion. Beginning 3000 years ago, landform stability allowed for soil formation that lasted at least 2000 years. The most recent episode of sedimentation may relate to uphill erosion from plow-based agriculture. These insights are considered for their potential to inform our understanding of karst landform responses to environmental and human impacts today.

**Mahony and Tunago, Adjoining but Contrasted Karst Plateaus in the NT, Canada**

**Derek Ford**

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West of Great Bear Lake (Lat. 65-66° N; 157 m asl) Canadian Shield rocks are overlain by bedded dolomites (Ordovician) forming a glaciated plateau dipping gently west. A spillway divides it into (i) 'Mahony Dome' (south side, ~1000 km<sup>2</sup>, ≤460 m asl) and (ii) 'Tunago Dome' (north, ~750 km<sup>2</sup>, ≤360 m asl). Both drain karstically, chiefly to springs in the spillway. MAT range is -7° to -10°C, precipitation 200-350 mm. Permafrost is widespread to continuous except beneath lakes. Mahony Dome is a plain, with droughty muskeg at the centre (the world's most extensive 'alvar?'), draining to sinkholes around the perimeter. Larger, glacier-scoured, depressions are/were occupied by karst lakes displaying a progression from (i) perennial lakes, with seasonal overflow; (ii) perennial, no overflow; (iii) seasonally

shrinking lakes; (iv) fully drained, with sinkholes: This is likely correlated with the groundwater hydraulic gradients. A small sector of Tunago Dome generally above ~325 m asl is similar, but terrain below it is dissected into tabular blocks (very large clints) with muskeg swamps between them. Deep hydraulic depressions scoured at upstream corners of clints or at narrowings in inter-clint corridors now function as the local sinkholes. This tabular terrain is the product of sub-glacial floods tearing up a pre-existing shallow karst pavement, a type of 'scablands' noted elsewhere in northern Canada, but not at this scale; the technical presence of permafrost does not inhibit modern karstic drainage here, in contrast to the situation in the centre of Mahony Dome.

**Investigating Geologic Controls of Western  
Pennyroyal Karst Region, Kentucky**

*Nahid, Gani<sup>1</sup>, Evan Crowe<sup>1</sup>, Kaily Scott<sup>1</sup>,  
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The Western Pennyroyal Karst region of Kentucky possesses the world's longest karst network, the Mammoth Cave. This landscape contains ~100 tributaries of the Green River watershed located within the Rough Creek Graben (RCG), a Cambrian age continental rift structure, where numerous fault-systems crisscross the Mammoth Cave and the tributaries. The RCG is dominated by macro-scale E-W trending rift border-faults. Numerous meso-scale structures also exist that are crucial to understand graben's deformation history as well as karstification. These structures are largely underexplored due to the presence of thick succession of sedimentary rocks and Quaternary sediments (~8 km) above the basement. We integrate field and remote sensing based analysis of the meso-scale structures and the tributary profiles from nine Green River sub-watersheds using 30-meter-resolution ASTER Digital Elevation Model (DEM). Our results suggest presence of distinct meso-scale faults mostly NE-SW and NW-SE trending. While lithology is the primary control of cave formation, these meso-scale faults likely played an important role in karst-landform development. Our river-profile analysis shows the presence of higher values (25) of normalized steepness-index, and ~300 knick-points. A large number of these knickpoints, which are unassociated with lithology, likely formed due to the neotectonic activity in the region. A preliminary positive-correlation between our mapped meso-scale fault

systems, geomorphic parameters, and the sinkhole locations suggest a likely relationship between these faults and the morphology of conduit systems. Our findings not only advance our understanding of a potential link between structures, karst, and geomorphic parameters but also help assess earthquake and landslide hazard risks.

## Hydrology

**A New Approach for Automatic Extraction of Karst  
Conduit and Matrix Recession Coefficients**

*Tunde Olarinoye<sup>1</sup>, Tom Gleeson<sup>2</sup>,  
and Andreas Hartmann<sup>1</sup>*

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About 10% of the world's population gets drinking water from karst groundwater. Groundwater flow in karst aquifers is dynamic and dominated by an interplay of fast and slow flow processes. Managing karst aquifers requires in-depth understanding of hydrogeological behavior. Spring hydrograph recession analysis has been used to understand flow dynamics and characterize karst aquifers for several years. Yet, they have only been applied manually to low numbers of karst spring hydrographs. An automatic recession analysis procedure to analyze large numbers of karst spring hydrographs is still not available. In this study, (1) we evaluate automatic recession extraction methods (REMs), originally developed for stream flow recession analysis for their ability to analyze karst spring hydrographs, (2) we propose simple adaptations of the REMS to allow their application for karst, and (3) we introduce new karst-specific recession analysis models (RAMs) that extract the recession coefficients of conduits and matrix of karst spring hydrographs including an estimation of their uncertainty. We identify the most suitable recession analysis approach by hypothesizing that the most realistic combination of REMs and RAMs provides the most distinguishable pairs of conduit and matrix recession coefficients. We use electric conductivity as an independent source of information to evaluate this hypothesis. Overall, our study will provide new directions for automatic recession analysis of karst systems using adapted extraction methods and karst-specific recession models; and therefore, help to infer about the comparative importance of conduit and matrix drainage in different catchments.

**A Blueprint for the Assessment of Inorganic Carbon Flow Paths in the Great Onyx Groundwater Basin, Mammoth Cave National Park**

Will White, Emeritus Professor of Geosciences, The Pennsylvania State University, State College, PA USA  
Chris Groves, Crawford Hydrology Laboratory, Western Kentucky University, Bowling Green, Kentucky USA

Assessment of the contribution of carbonate rock terrain to the global carbon budget is complicated by the interrelationships of carbonate rock dissolution and precipitation, diversity of flow paths and travel times of water moving through the soil and rock mass, and chemical and isotopic interchanges along these flow paths. The Great Onyx Groundwater Basin provides a testbed for untangling these relationships. The Great Onyx Groundwater Basin is an essentially pristine karst flow system developed within the alternating carbonate and clastic rocks of Mammoth Cave National Park's Hilly Country. The nearby, deeply incised, Green River provides roughly 100 m of relief. There is a sequence from upper clastics, the intermediate Haney Limestone, the ridge-forming, massive Big Clifty Sandstone, and down to base level, the massive Girkin and Ste. Genevieve Limestones. More than 20 km of cave passages provide access to seepage flows, shaft flows, and base-level streams for sampling and flow measurements. Atmospheric CO<sub>2</sub> exchanges with organic-derived soil CO<sub>2</sub> and with sequestered CO<sub>2</sub> in the carbonate bedrock as meteoric water makes its way down the gradient to ultimately discharge at a spring at river level. CO<sub>2</sub> consumption by dissolution can be traced as well as re-sequestration by speleothem deposition. Net gain and/or carbon loss can be traced along each of multiple flow paths, leading to an overall carbon budget for the Great Onyx Basin

**In-cave Tracing to Measure Discharge in the Great Onyx Flow System, Mammoth Cave National Park, Kentucky**

Jessica Williams, Chris Groves, and Lee Anne Bledsoe  
<sup>1</sup>Crawford Hydrology Lab, Western Kentucky University, 1906 College Heights Blvd. Bowling Green, KY 42101

Great Onyx Cave is located in Mammoth Cave National Park, and due to its nearly pristine nature, it is an incredible area to study hydrologic and geochemical processes related to landscape evolution, nutrient cycling, and landscape/atmosphere interactions associated with the global carbon cycle. Understanding this relatively pristine cave system can act as a control for researching human impacts on similar water systems. Groundwater tracing is one of the best methods available to understand flow direction and aquifer characteristics in karst drainage basins. Using

both salt and dye tracer dilution methods, discharge and hydrologic connection of key in-cave monitoring locations are determined. Groundwater travel times between in-cave locations, calculated volume, and the subsurface pathway network identified are shown to better inform geochemistry research and our 3-D conceptual model of the Great Onyx Basin.

## Modelling

**Representing Uncertainty with Diverse Model Ensembles: A Test Case in an Alpine Karst System**  
*Chloe Fandel<sup>1</sup>, Ty Ferré<sup>1</sup>, Zhao Chen<sup>2</sup>, Nico Goldscheider<sup>2</sup>*  
<sup>1</sup>Department of Hydrology and Atmospheric Sciences, University of Arizona PO Box 210011 Tucson, AZ 85721;  
<sup>2</sup>Institute of Applied Geosciences, Karlsruhe Institute of Technology

Karst aquifers are difficult to model because the heterogeneous nature of groundwater flow through conduits, rather than through distributed pore spaces, leads to high structural uncertainty. Most existing models rely either on detailed conduit maps, or on effective flow parameters approximating a porous medium. Both approaches have significant failings, because karst systems are rarely fully mapped, and their flow behavior is fundamentally different from porous aquifers. Our approach links three components: geologic modeling, conduit network generation, and pipe flow modeling. We use pre-existing data from a long-term research site, the Gottesacker karst system in the German/Austrian Alps. First, we build several geologic models in GemPy, a Python package. Each geologic model is fed to the Stochastic Karst Simulator, a pseudo-genetic conduit evolution model, generating many conduit network maps. For each network, we estimate hydraulic parameters, and model the flow behavior using the E.P.A. Storm Water Management Model. This yields an ensemble of competing models, organized into a model tree recording the geologic structure, conduit network map, and hydraulic parameters for each model. The models in the ensemble will be ranked based on the fit of model-predicted spring discharge to observed data, and a subset of high-performing models used to project future discharge under different scenarios. We expect that the benefit of this structurally diverse model ensemble is that it will more fully represent the range of possible system behaviors. Finally, the ensemble will be compared to the known conduit network, to assess the effectiveness of our approach.

## Resource Management, Protection and Education

### Lampenflora, the Alien of Show Caves: Monitoring and Treatments

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Caves are often subject to tourist adaptations, causing an irreversible impairment of the bio-geochemical equilibria, which are still not entirely understood, due to the scarcity of information. Between the most worrisome consequences, there is the development of photoautotrophic and mixotrophic communities, called “lampenflora”, growing because of artificial lighting. They are considered the main responsible of the surface alterations, with possible damaging effects, jeopardizing the speleothem conservation, included the still scarcely known vermiculations. This work aims to shed light on the efficacy of monthly chemical (15% H<sub>2</sub>O<sub>2</sub> and commercial bleach) and physical (one night UV-C) growth-control treatments, as well as the triggered alteration processes, on small test surfaces covered by lampenflora, with and without vermiculations. The study, carried out in the tourist lit trail of the Pertosa-Auletta Cave (southern Italy), reports preliminary findings on the photosynthetic activities of such communities, before and after the treatments. The analysis of maximal photochemical yield (MINI-PAM, Walz) was performed through *in situ* non-destructive chlorophyll fluorescence measurements. The preliminary findings of the research show promising results, highlighting a reduced photosynthetic activity of the lampenflora already after the first two treatments. Indeed, pre-treatment measurements on the dark-adapted surfaces, with and without vermiculations, showed Fv/Fm values between 0.766-0.713 and 0.710-0.663, respectively. After the first H<sub>2</sub>O<sub>2</sub> and bleach treatments, the maximal PSII photochemical efficiency was similar, on average 0.024, and did not change for a month nor after the second treatment, indicating an almost complete reduction of biological activity. For the surfaces interested by UV-C treatments, no detectable effect occurred in relation to the photosynthetic activity, suggesting the need to increase the number of such treatments to twice a month, or even weekly.

### Moroccan caves and their implications in the scientific, geoeducational and geotouristic programs through

### speleological activities.

Taha Younes Arrad, Department of Geology, Faculty of Sciences, Chouaib Doukkali University, El Jadida, Morocco.

Morocco is world-wide known for its great geodiversity, notably its rich and abundant karstic occurrences. Although, abundance of carbonate deposits gives rise to a very large number of caves, avens and underground cavities endowed with remarkable speleothems and concretions, it still rarely studied and assessed as geo-heritage component. Moreover, the Moroccan caves yielded so far unexpected human and animal remains, which contributed to the understanding of the origin and evolution of our species and their paleoecosystems. The most relevant examples are the unearthed oldest skull of Homo sapiens from Jbel Irhoud Cave (Hublin et al., 2017), and the ancient human DNA recovered from the Pigeons cave, near Taforalt (van de Loosdrecht et al., 2018). Beside the scientific significance, the karst has cultural and historical magnitude that is reaching out to communities according to their own habits and traditions. However, the combined action of natural triggers and anthropogenic harms weakens the underground environment and threatens the integrity of karst in all its aspects. Accordingly, the use of caving activities and their adjustment to the target group allows a scientific outreach and a direct awareness-building on the importance of the underground geoheritage. This contribution aims to present and highlight examples of scientific, educational and touristic initiatives carried out by civil society bodies to advocate for the protection of the karst geoheritage in Morocco. It will also discuss the different future outlook for the conservation of these natural resources and their implication through the process of sustainable socio-economic development of the local community

### Landscape perception and traditional knowledge for sustainable development of UNESCO Škocjan Caves Area in the Classical Karst, Slovenia (Europe)

Jasna Fakin Bajec<sup>1</sup>, Katja Hrobat Virloget<sup>2</sup>, Petra Kavrečič<sup>2</sup>, Dimitrij Mlekuž<sup>3</sup>, Nadja Penko Seidl<sup>4</sup>,

<sup>1</sup>Research Centre of the Slovenian Academy of Science and Arts, Institute of Culture and Memory Studies

<sup>2</sup>University of Primorska, Institute for Intercultural Studies of the Faculty of Humanities

<sup>3</sup>University of Ljubljana, Faculty of Arts, Department of Archaeology / Institute for the protection of cultural heritage of Slovenia, Centre for preventive archaeology

<sup>4</sup>University of Ljubljana, Biotechnical Faculty, Department of Landscape Architecture

Development cannot be sustainable without including the culture of local residents, who, through historical

periods, have perceived, interpreted and used natural resources according to their needs and available knowledge. Any sustainable management of landscape should respect the meaning and importance that local people ascribe to material, social and spiritual practices. Special emphasis should be put to activities developed in balance with nature and its resources (e.g. caves, herbs, stones). Our ancestors had spiritual and emotional attitude towards nature and needed natural resources for survival. Their knowledge, skills and rituals, therefore could be effectively adapted to alleviate the techno-industrial overload of nature and to revitalize a cultural landscape. Although culture is recognized as an intrinsic part of the human experience and a driver of sustainable development (Culture for the 2030 Agenda), many challenges related to theory into practice have to be solved by different approaches. One of them is how to involve landscape perceptions and traditional knowledge and skills to future development and young generations. In this context, the main purpose of the paper is to reflect on specific past material, ritual (spiritual) and social elements of the wider UNESCO Škocjan Caves Area in the Classical Karst, Slovenia (Europe). By presenting the meaning and function of sacrificial practices in the caves in the Škocjan area, the mythical landscape features and the community's knowledge of using herbs in local dishes preparation, the paper will show how intangible cultural heritage can meaningfully be used in finding ways to reach sustainable development goals.

#### **Monitoring Karst Aquifers in North Alabama for the Protection of Sensitive Aquatic Biota**

Gheorghie M.L. Ponta<sup>1</sup>, Stuart W. McGregor<sup>1</sup>, Rebecca A. Bearden<sup>1</sup>, and Randall Blackwood<sup>2</sup>

<sup>1</sup>Geological Survey of Alabama 420 Hackberry Lane Tuscaloosa, AL 35401; <sup>2</sup>Alabama Department of Conservation and Natural Resources

Cave ecosystems in north Alabama provide vital habitat for numerous conservation concern species, including the federally endangered Alabama Cavefish (*Speoplatyrhinus poulsoni*), Alabama Cave Shrimp (*Palaemonias alabamiae*), and Gray Bat (*Myotis grisescens*), as well as other conservation priority species such as the Southern Cavefish (*Typhlichthys subterraneus*), Alabama Cave Crayfish (*Cambarus jonesi*), and Phantom Cave Crayfish (*Cambarus pecki*), among others. The Alabama Cave shrimp population and water quality in Bobcat Cave on Redstone Arsenal in Madison County, Alabama, have been monitored since 1990. Key Cave, found in Lauderdale County, Alabama, is a satellite of the Wheeler National Wildlife Refuge and has been des-

ignated as critical habitat for the Alabama Cavefish, which is known only from pools within that cave. The aquatic fauna in Cathedral Caverns is diverse, although none of its members are currently afforded protection. Groundwater studies in these cave systems have been conducted to determine in recharge areas and aquifer characteristics to enable local, state, and federal agencies and interested citizens to develop, manage, and protect the water resources that support these species. Water level, specific conductance, and temperature data have been collected using data loggers on an hourly/daily schedule to evaluate and document flow conditions and seasonal flow variability, to establish a water level baseline, and to determine aquifer characteristics in the area within and around these caves.

#### **Collaborative Management with Local Communities for the Conservation of Karst Resources at Hin Nam No Protected Area, Laos**

Terry Bolger, IUCN Cave & Karst Working Group, Vientiane Vientiane Capital 01000, Lao People's Democratic Republic

Hin Nam No is a karst protected area in central Laos, for which a nomination as a natural World Heritage site is being prepared. Due to limited financial and human resources, however, there is a lack of capacity and information to effectively manage and monitor the protected area. In response, a collaborative management (co-management) system has been established for Hin Nam No, in which local communities play an active role, and have more powers and responsibilities for management of the natural resources on which they depend. Thus, there is a shared goal of biodiversity and geodiversity conservation and poverty alleviation in and around Hin Nam No. There are 18 'guardian' villages surrounding Hin Nam No, comprising about 8000 people. Village rangers from the guardian villages are involved with patrolling and monitoring, and assist with exploration and field research in Hin Nam No. Village ecotourism guides from several villages guide tours to caves and walks in the spectacular karst landscape of Hin Nam No. There has been a 16% improvement in management effectiveness since co-management of Hin Nam No was initiated in 2014, with major improvements in technical capacity and management skill. Further work on capacity enhancement, implementation of management plans and adaptive management, and sustainable financing will be required to sustain this system of co-management, and thus protect and conserve the karst resources of Hin Nam No.

**How well is cave and karst geoheritage protected by UNESCO protected area designations?**

*John Gunn, University of Birmingham (UK)*

There are four UNESCO protected area designations: World Heritage Sites (WHS), Global Geoparks (GG), Ramsar Sites (RS) and Biosphere Reserves (BR). Databases have been compiled listing sites in each category that contain, or are thought to contain, features of cave and / or karst interest (the "and / or" is because some caves in protected areas are not associated with surface karst landforms because they were not formed by dissolution, for example lava caves). The databases, which are still being cross-checked include 96 WHS, 60 GG, 124 RS and 180 BR. The total number of individual protected sites will be less than the sum of the parts as some sites have multiple designations. In some of the WHS and most GG the cave and/or karst geoheritage interest is explicitly recognized and protected but in those WHS designated for other interests such as cultural sites and in RS and BR the geoheritage may go unrecognised and unprotected. The data bases are seen as a first step in assessing interest features and will be followed up by an information campaign aimed at improving awareness and management.

**Karst management in Apuseni Nature Park (Romania)**

*Zoltán Imecs,  
Babes-Bolyai University Cluj-Napoca, Romania*

Apuseni Mountains are a mostly forest covered mountainous area rich in exokarst and endokarst landforms. At present, 760 km<sup>2</sup> of the mountains are under the protection of Apuseni Nature Park (IUCN Category V). There are more than 1500 caves in the area. They are classified according to their scientific values, national or local importance, but in certain cases access to the caves is not in agreement with their classification or scientific importance. The caves located in the park are not open to the public, some of them can be visited with a special permit. There are four show caves (Bear's cave, Scărișoara cave, Vârtope cave, Poarta lui Ionele cave). Their management is organized in different ways. These caves are popular tourist targets and we analyze visitor numbers statistics to present their significance and timely changes. Problems related to cave management are waste disposal near the caves (in sinkholes), damage in caves and occasional accidents due to irresponsible cave tourists (not in show caves). Besides caves, gorges and collapse sinkholes are also popular karst-based tourist targets in the Park. Recently, paved roads were improved in the area, which helps tourism, but it also increases the environmental burden. The complex impact of tourism is evaluated in this study.

While tourism is rather concentrated to the popular destinations, forestry and to a smaller extent, traditional farming still have a significant areal impact on the karst landscapes. We have to mention that more than 10000 inhabitants live in 55 settlements inside the Park.

**Geotourism and Local Development in NP Slovak Karst: Behaviour Survey of Local People, Tourists and Experts**

*Alena Gessert<sup>1</sup>, Janetta Nestorová-Dick<sup>2</sup>,  
Lenka Bryndzov<sup>2</sup>, Tamás Telbisz<sup>1</sup>*

*<sup>1</sup>Department of Physical Geography,*

*Eötvös Loránd University, Budapest, Hungary*

*<sup>2</sup>Institute of Geography, Faculty of Natural Sciences, P.J.*

*Šafárik University, Jesenná 5, Košice 040 01 Slovakia,*

This contribution provides an insight into the relationship between man and the environment in the Slovak Karst National Park (the most developed karst area of Slovakia). At present, research into the interconnection of these two components is playing an increasingly important role. The local population plays one of the most important roles in relation to the karst landscape. We also analyze the issue from the perspective of three other research groups. Each of these groups shows a special interaction with the studied area. The result is a summary of all the attitudes by which we evaluated the common and different views on various aspects of the national park. Common views include a positive attitude of all components to the development, greater promotion of the national park and the preservation of the karst landscape. The values, the role of the national park and the attitude to the protection of the area showed some differences. Based on this information, we can also determine the changing role of man in the protected area from the past to the present. Karst areas are characterized by many specifics, which distinguish them from other protected areas. In addition to the fact that man affects the environment, the environment itself has an effect on humans. Such effects can have various advantages or disadvantages that one needs to deal with. This research is supported by NKFI, Hungary.

**Forest Management Considerations and Best Management Practices on Karst Landscapes: A Lesson in Evidence-Based Management Guidelines**

*Cory Holiday, Cave and Karst Program Director,  
The Nature Conservancy,*

*Stuart Hale, The Nature Conservancy,*

*Christopher Groves - Western Kentucky University*

When The Nature Conservancy initiated a multi-state

forest management program aimed at improving conservation forestry while maintaining forest products revenue, we immediately identified a need for karst specific forest management guidance. Almost all other conservation priorities are adequately supported through the Forest Stewardship Council forest management prescriptions. After a lengthy review of existing guidance we found inconsistent recommendations for forestry on karst and a general lack of supporting evidence rationale. Subsequently The Nature Conservancy reviewed a variety of literature resources seeking support and guidance to create and defend measurable forest management best practices for karst landscapes. The Nature Conservancy ultimately did create forest management recommendations for karst landscapes, but possibly more important is the identified data gaps that would likely lead to improved conservation forestry in karst landscapes.

#### **How Visitation is Affecting Air Quality in Carlsbad Cavern**

*Sonia Meyer, Carlsbad Caverns National Park,  
Carlsbad, NM 88220, USA*

Carlsbad Caverns National Park is monitoring carbon dioxide (CO<sub>2</sub>) in Carlsbad Cavern to assess the park's current conditions as a component of a Visitor Use Management (VUM) study. Elevated CO<sub>2</sub> concentrations can impact visitor safety, cave conservation, and visitor experience. This preliminary work establishes standard operating procedures for a future yearlong study. CO<sub>2</sub> levels were monitored from June to July 2019 at a 5 minute sampling interval in three locations: lower elevator waiting area, Big Room Junction, and King's Palace. Two major limitations of this study are the sparsity and quality of data due to the short two-month monitoring period, various data losses, and the unreliability of the data due to mathematical corrections for automatic baseline calibrations. CO<sub>2</sub> levels increased consistently in June and July of 2019. While the CO<sub>2</sub> levels decreased in the evening, they did not return to starting levels. Visitor CO<sub>2</sub> fluxes were cumulative over time during these two months. There was a positive correlation between daily visitation numbers and CO<sub>2</sub> levels at the elevator and Big Room Junction. There was not enough data from the King's Palace sensor for data analysis. Given the limitations of this study, these results are preliminary and should not be extrapolated past June and July of 2019. Carbon dioxide monitoring should be continued for at least a year; with more data, stronger conclusions and seasonal patterns can be determined.

#### **Monitoring karst aquifers in North Alabama for the protection of sensitive aquatic biota**

*Stuart McGregor, Gheorghe M. L. Ponta,*

*Rebecca A. Bearden, Randall Blackwood  
Geological Survey of Alabama,  
Tuscaloosa Alabama 35401*

Cave ecosystems in north Alabama provide vital habitat for numerous conservation concern species, including the federally endangered Alabama Cavefish (*Speoplatyrhinus poulsoni*), Alabama Cave Shrimp (*Palaemonias alabamae*), and Gray Bat (*Myotis grisescens*), as well as other conservation priority species such as the Southern Cavefish (*Typhlichthys subterraneus*), Alabama Cave Crayfish (*Cambarus jonesi*), and Phantom Cave Crayfish (*Cambarus pecki*), among others. The Alabama Cave shrimp population and water quality in Bobcat Cave on Redstone Arsenal in Madison County, Alabama, have been monitored since 1990. Key Cave, found in Lauderdale County, Alabama, is a satellite of the Wheeler National Wildlife Refuge and has been designated as critical habitat for the Alabama Cavefish, which is known only from pools within that cave. The aquatic fauna in Cathedral Caverns is diverse, although none of its members are currently afforded protection. Groundwater studies in these cave systems have been conducted to determine in recharge areas and aquifer characteristics to enable local, state, and federal agencies and interested citizens to develop, manage, and protect the water resources that support these species. Water level, specific conductance, and temperature data have been collected using data loggers on an hourly/daily schedule to evaluate and document flow conditions and seasonal flow variability, to establish a water level baseline, and to determine aquifer characteristics in the area within and around these caves.

#### **Environmental Monitoring in Škocjan Caves, Slovenia**

*Franci Gabrovsek, ZRC SAZU, Karst Research Institute,  
Postojna Slovenia 6230 Slovenia*

*Borut Peric,  
Škocjan Caves Regional Park, Slovenia*

Environmental impact of touristic use in a cave can be manifold, from direct physical impact on the bedrock, cave forms and sediments, to subtle changes in cave environment. The light can cause growth of lampenflora, people are net heat, CO<sub>2</sub> and microbial sources, which can cause significant changes in the cave environment. Impact can only be assessed based on long term monitoring of environmental parameters. Škocjan Caves in Slovenia have experienced a fast growth in number of visitors, which has almost doubled during the last decade, and is now approaching 200,000 per year. To detect and evaluate the potential changes in cave environment, a network of online meteorological stations, lampenflora test sites and other measurements of environmental parameters have been established. We present the set-up and results of the first two years of mon-

itoring in Škocjan Caves. Data revealed the main natural and anthropogenic driving mechanisms of cave atmosphere. As anticipated, the environmental impact of tourist visits differs seasonally and from site to site within the cave. We discuss the variations in relation to the cave morphology, distribution of entrances, changes in the outside atmosphere and the flux of tourists. The focus of the research is to identify the potential long-term or irreversible changes, which could indicate that the cave carrying capacity is exceeded. This may require introduction of management changes like limiting and/or redistributing the number of visitors, actions, which will be in any case required to provide educative and eventful experience for the visitors.

### **Virtual Field Trips to your Park - An Inexpensive Way to Reach the Masses**

*Jennifer Shackelford, Education Specialist,  
Mammoth Cave National Park,  
Mammoth Cave, Kentucky USA*

In this presentation (powerpoint and talk-question/answer session) participants will learn about how Mammoth Cave National Park implemented a virtual field trip program. This program cost less than \$100 in supplies and has helped share their national park with thousands over the past three years since it was implemented. In this session participants will learn how the park recruited teachers from across the United States to participate and the free platforms that are available to use for virtual field trips.

### **Karstic National Parks' Roles and Potentials – Views and Opinions from Tara National Park, Serbia**

*Tamás Telbisz<sup>1</sup>, Jalena Calic<sup>2</sup>, Jalena Kovačević-Majkić<sup>2</sup>,  
Jovana Brankov<sup>2</sup>, Jasna Micić<sup>2</sup>, and László Mari<sup>1</sup>*

<sup>1</sup>*Department of Physical Geography, Eötvös Loránd University, Fadrusz u. 12 Budapest, Hungary 1114;*

<sup>2</sup>*Geographic Institute "Jovan Cvijić" Belgrade, Serbia*

Karst terrains are often protected as national parks (NP) thanks to their spectacular landforms and biological features. These areas are often relatively rarely inhabited, which contributes to the preservation of all forms of natural heritage. Considering the national parks, the general (simplified) question is, whom they should serve: the protection of nature, the well-being (and education) of tourists or the benefit of local people. Naturally, all of these goals are important, but sometimes contradictory. The above question arises more specifically, when the area of the NP has been inhabited for centuries, but depopulation and ageing are the dominant processes today. The above facts are valid for Tara NP – our case study area, established in

1981 in western Serbia. The area is a typical medium mountain continental karst with doline dotted karst plateaus. Its most significant landmarks are gorges, whereas caves are small, vertical and not suitable for tourism. The biological values (endemic species, large bear population) were also crucial in the foundation of the NP. During its 38-year long history, the social-political context (socialism, war, market economy) has been widely varied, which had an impact on the operation and goals of the NP. In our study, we conducted a questionnaire survey asking local people, tourists, NP employees and managers, as well as external experts, about how they perceive the advantages and drawbacks of Tara NP. The systematized results are intended to contribute to solving the management issues in the nature–tourism–community triangle.

### **The 2020 Mammoth Cave National Park Natural Resource Condition Assessment**

*Cathleen Webb<sup>1</sup>, Chris Groves<sup>2</sup>, Autumn Singer<sup>2</sup>, Lee Anne Bledsoe<sup>2</sup>, Rick Toomey<sup>3</sup>, Bobby Carson<sup>3</sup>, Katie Algeo<sup>4</sup>*

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A new, comprehensive analysis of Mammoth Cave National Park and its resources concludes that this is a well understood, well cared for, and carefully protected national park. Many resources are in good condition or even improving. Improvements in regional coal combustion have, for example, raised rainfall pH by a whole unit, dropped rain SO<sub>4</sub> by 75%, and improved visibility. The Green River has nationally significant biodiversity, and the park protects threatened and endangered species, sensitive wetlands and rare plants. There are also challenges: White Nose Syndrome has killed at least 70% of at least three species of bats (though other species may be filling these niches), emerald ash borers threaten the park's ash trees, and one day hemlock wooly adelgids may impact the beautiful hemlocks of Bylew Creek. The largest threat to the underground landscape is contamination draining agricultural and other land use from outside of the park. Interrelationships become clear in this kind of holistic examination. Slender glass lizards and some bird species, once relatively common in the pre-park open farmland, are being extirpated as forest trees take over. Where possible, conclusions are based on quantitative data. The view of

the Milky Way streaming across the park's beautiful dark sky is increasingly rare in the eastern US: most of the park has a Class 4 rating on the Bortle Scale as well as consistent Unihedron Sky Quality Meter (SQM) readings over 21.0, which qualify it for Silver Tier Status from the International Dark Skies Association for "exemplary nighttime landscapes."

**Cave Conservation and Restoration:  
Workshops Around the Globe**

*Val Hildreth-Werker, National Speleological Society,  
Jim C. Werker, Conservation Division Chief,  
National Speleological Society*

We will introduce philosophies and methods of current best practices in cave restoration with an overview of international workshops. Coordinating through an individual or team in the host country, we structure classroom sessions and in-cave activities from science-based techniques described in peer-reviewed chapters of the volume titled, *Cave Conservation and Restoration*. Classroom discussions and practical activities focus workshop students to identify, analyze, and mitigate negative anthropogenic cave impacts. Following impact assessment exercises, teams gain hands-on experience in restoring natural cave surfaces, sediments, and speleothems harmed by development, infrastructure, and tourism in show caves. Some workshop-groups mitigate the results of untutored visitation in wild caves. Each workshop design is appropriate to the needs of the cave site. Guided by the principle of do no harm, we explore methods for assessing and removing contemporary graffiti while identifying and protecting cultural and historic markings; introduce techniques and tools for repairing broken speleothems using archival, cave-safe materials and epoxies; emphasize practices to prevent cross-contamination; and encourage minimum-impact caving ethics. With opportunities for in-depth analysis, application of principles, and fine-tuning of skills, workshop participants practice decisions in sustainable cave conservation management.

**Karst Management in Apuseni Nature Park (Romania)**

**Zoltán Imecs<sup>1</sup>, Tamás Telbisz<sup>2</sup>, Alin Mos<sup>3</sup>,  
and Nicu Scrob<sup>3</sup>**

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<sup>2</sup>*Department of Physical Geography, Eötvös Loránd University, Budapest, Hungary;*

<sup>3</sup>*Apuseni Nature Park, Sudrigiu, Romania*

Apuseni Mountains are a mostly forest covered mountainous area rich in exokarst and endokarst landforms. At present, 760 km<sup>2</sup> of the mountains are under the protection of Apuseni Nature Park (IUCN Category V). There are more than 1500 caves in the area. They are classified according to their scientific values, national or local importance, but in certain cases access to the caves is not in agreement with their classification or scientific importance. The caves located in the park are not open to the public, some of them can be visited with a special permit. There are four show caves (Bear's cave, Scărișoara cave, Vârtope cave, Poarta lui Ionele cave). Their management is organized in different ways. These caves are popular tourist targets and we analyze visitor numbers statistics to present their significance and timely changes. Problems related to cave management are waste disposal near the caves (in sinkholes), damage in caves and occasional accidents due to irresponsible cave tourists (not in show caves). Besides caves, gorges and collapse sinkholes are also popular karst-based tourist targets in the Park. Recently, paved roads were improved in the area, which helps tourism, but it also increases the environmental burden. The complex impact of tourism is evaluated in this study. While tourism is rather concentrated to the popular destinations, forestry and to a smaller extent, traditional farming still have a significant areal impact on the karst landscapes. We have to mention that more than 10000 inhabitants live in 55 settlements inside the Park.

## Summary of Workshop Outcomes

Recordings of all sessions are accessible via the Karst 2020 website and official YouTube channel.

### **Stronger Together: A Global Conversation**

The Stronger Together panel included a diverse group of experts from various disciplines that shared their perspectives on building partnerships, improving communication, and the intersectionality of biodiversity, landscape management, and natural and cultural heritage. You can view their conversation at our Karst 2020 YouTube Channel ([youtube.com/channel/UCYKKEzTAscVWhYukm0e2Zrg](https://youtube.com/channel/UCYKKEzTAscVWhYukm0e2Zrg))

### **Plenary Session: Sustainability and Community**

Managers and researchers from across the globe shared perspectives on the strengths and challenges to managing karst resources and the UNESCO programs designed to protect these environments. Topics covered a broad spectrum including collaborative management, efficacy of UNESCO protected area designations in safeguarding cave and karst geogheritage, geotourism roles and potentials, public perception, use of traditional knowledge to guide karst management, and geoeducational and geotouristic opportunities offered by speleological activities.

### **Technical Sessions and Field Trips**

Presentation topics ranged from cave conservation techniques, environmental education, community engagement, resource protection assessment, and scientific and cultural research from across the globe. Formats vary from traditional PowerPoints to films to story maps and informal interviews. Find additional information and recordings of each session via our website or YouTube channel.

### **Workshop Sessions**

#### ***Exploring Best Practices in Data Management, Integration, And Visualization***

Facilitators: Sarah Arpin, Geologist II, Kentucky Geological Survey, and Pat Kambesis, Center for Human Geoenvironmental Studies, Department of Earth Environment and Atmospheric Sciences, Western Kentucky University

Facilitators of this fun and productive session covered data management from alpha to omega, introducing tools and methods for managing individual data sets to publishing and sharing collaborative databases. Participants discussed challenges and shared data quality standards. With participant input, the facilitators creat-

ed a resource directory that is available at <https://karst2020.com/supplemental-materials/> and through KGS outlets.

***Significance of Cultural Heritage in Karst Landscape Management: 2030 Agenda for Sustainable Development.*** Facilitators: Darja Kranjc, Higher Nature Protection Counselor, Skocjan Caves Park, Slovenia, and Jasna Fakin Bajec, Institute for Culture and Memory Studies, Research Centers of the Slovenian Academy of Sciences and Art

This engaging and informative workshop session included presentations from both of the facilitators, Darja Kranjc and Jasna Fakin Bajec, on the importance and value in cultural heritage to karst resource protection and implementation of sustainable practices. They introduced how at Skocjan Caves they are using ancestor wisdom to address problems of the modern world and build a treasury of traditional lifeways to address challenges such as water conservation and climate change. During the café conversation following the presentations, participants were given time to contribute examples of cultural heritage that does or could inform sustainable practices in their BR, protected area, or field of study and then determine what sustainable development goals related to that particular activity. Discussions following the group activity stressed using an integrative approach to build an army of local stakeholders by showing communities their intrinsic value in both tangible and intangible aspects of their culture. Participants agreed that instilling pride in one's place and culture seeds responsibility to our environment.

***Gazing Deeply: The Art and Science of Mammoth Cave*** Leaders: Dr. Chris Groves, University Distinguished Professor of Hydrogeology, and Tiffany Isslehardt, Curator and Development Manager, Kentucky Museum, Western Kentucky University

Dive into the all that is Mammoth Cave in this virtual tour of the *Gazing Deeply* exhibition, a collaborative effort between Mammoth Cave National Park and Western Kentucky University arts and science faculty and students that highlights one of the most well-known and vital karst landscapes in the world. One special feature of the exhibit includes art interpretations from an international group of renown karst scientists. (<https://www.wku.edu/kentuckymuseum/exhibits/gazingdeeply.php>) The facilitators also discussed the process of curating an interdisciplinary exhibit, the four

and organizations to connect people with nature and highlight environmental issues.

***Citizen Science, Research and Land Management in Karst*** *Facilitator: Ben Tobin, Karst Hydrogeologist, Kentucky Geological Survey*

This session took a round robin open-discussion approach with a diverse group of cavers, scientists, and managers tasked with proposing ways to improve how to work together, broaden our understanding of cave resources and management, and continue to build relationships. The discussion began by description of the types of data collected by caver citizen scientists that were most useful to the group. Participants next identified existing gaps in caver-derived data and overall challenges to managing karst environments. This portion of the workshop centered on the need for improved data quality, access, and management as well as better communication with legislators and the public to build greater awareness of the importance and fragility of karst resources. Finally, the group resolved steps forward including more inclusive access to affordable training opportunities, implementation of modern data collecting programs, enhanced mentorship between managers, researchers, and citizen scientists, communication with legislators to develop a standard definition of cave/karst resources, and easy to understand dialog with the public to foster increased ownership and stakeholder engagement. Participants agreed to work on creating guidelines for better communication between all players in the protection of fragile karst resources.

***CaveMAB*** *Facilitators: Clayton Lino, Speleologist, Director, Mata Atlantica Biosphere Reserve and Lee Anne Bledsoe, Western Kentucky University*

This session brought together the newly formed CaveMAB network, an informal, global network of cave and karst [biosphere reserves](http://www.cavemab.com) ([www.cavemab.com](http://www.cavemab.com)). The workshop started with a message of encouragement and support from Miguel Cluesner-Godt, Director, UNESCO Division of Ecological and Earth Sciences and Secretary to the Man and the Biosphere Program. Clayton Lino then briefed the group on 2018/2019 CaveMAB activities and the recently drafted Declaration of Objectives. He then presented several examples of best practices from Brazil and the importance of sharing experiences in the CaveMAB network. George Veni, UIS President and NCKRI Director, then introduced the UIS International Year of Caves and Karst

and shared some ideas for how CaveMAB could support the initiative. Lee Anne Bledsoe then lead the group in two breakout sessions – the first to provide the opportunity for workshop participants to introduce themselves and as a new network get to know one another, the second breakout session asked participants to propose one collective action that CaveMAB could take to support the IYCK 2021 and celebrate the 50<sup>th</sup> Anniversary of MAB. The group decided to form a subcommittee to coordinate correspondence and selection of the proposed ideas (International Cave Clean-Up Day, Biodiversity parade, collaborative film showcasing CaveMAB members). Other topics discussed in the wrap-up of the session included the importance of focusing on youth and education in our future activities, continuing to build the database of cave/karst BR resources with partners such as the UIS, IUCN, national speleological associations, etc., formation of a steering committee, and the potential to hold our first in-person meeting in 2021 during an associated meeting or conference. All participants were invited to join the network ([cavemab.com](http://cavemab.com)), help build our resource database and correct contact information, provide review of the Declaration of Objectives, and offer nomination for the steering committee. The CaveMAB network coordinators and IYCK Subcommittee will provide additional information to workshop participants in Fall 2020.

***Teaching Karst Through Environmental Education*** *Facilitators: Jennifer Shackleford, Education Specialist, Mammoth Cave National Park and Dr. Jeanine Huss, Professor, School of Teacher Education, Western Kentucky University*

This session presented detailed examples of Mammoth Cave National Park and WKU youth environmental education (EE) programs as well as their teaching training initiatives. The facilitators offered pro-tips and methods to best engage students in the classroom, virtually, and through field visits and day camps. Dr. Huss and Ms. Shackleford shared how the developed hands-on activities, physical models for the classroom, and pre-recorded EE ranger lessons informed by specific curriculum guidelines. Participants discussed the difficulty of connecting surface landforms and activities to subsurface hydrology and water quality in some karst settings where students are unable to enter caves. The group also agreed to share lesson plans and education resources among each other and suggested events like *The Great American Teach In*, sponsored by the National Education Association in support of the American Education Week, as a way to reach students in communities across the US. CaveSim (<https://www.cavesim.com/>) and other cave simulation models and traveling exhibits were also discussed.

***Tools and Techniques for Urban Karst Hydrology and Hazard Monitoring and Management***

Leaders: Dr. Jason S. Polk and Adam Shelley, Center for Human Geoenvironmental Studies, Department of Earth Environment and Atmospheric Sciences, Western Kentucky University

This workshop session included an informative and in-depth presentation led by Dr. Jason Polk on historic to modern karst hydrology and hazard monitoring in Bowling Green, Kentucky and the challenges of urban settings and development to karst field studies. Participants 'toured' monitoring sites via live videos, satellite imagery, and interactive maps. Mr. Adam Shelley also shared detailed information about the development of

their injection well monitoring network and subsequent modeling efforts. The facilitators also introduced data management techniques, specialized software, and presented research results for on-going water quality and quantity studies. One particular highlight was the introduction of the Urban Karst Aquifer Resource Evaluation (UKARE) toolbox to assess vulnerability and risk for site selection. The workshop wrapped up with a local water quality case study and CHNGES public outreach efforts as well as some guiding principles for improved karst monitoring and management. For more information check out <https://www.wkuchnges.com/> and <https://www.underbgky.org/>.



Conservation of Fragile Karst Resources Proceedings—August 18-20, 2020

CONSERVATION OF FRAGILE KARST RESOURCES: A WORKSHOP ON SUSTAINABILITY AND COMMUNITY

TUESDAY, AUGUST 18, 2020		ALL TIMES IN CENTRAL DAYLIGHT SAVINGS (-5 HOURS GMT)	
7:30	MEETING ROOM AND VIRTUAL HELP DESK OPENS		
8:00	WELCOME and OPENING REMARKS		
8:30	SPECIAL MESSAGE: 2021 INTERNATIONAL YEAR OF CAVES AND KARST, UIS PRESIDENT, GEORGE VENI		
8:45	STRONGER TOGETHER: A GLOBAL CONVERSATION		
9:30	BREAK		
	<b>PLENARY SESSION: SUSTAINABILITY AND COMMUNITY</b>		
9:45	Bolger, Terry	Collaborative Management with Local Communities for the Conservation of Karst Resources at Hin Nam No National Park, Laos	
10:00	Gunn, John	How Well is Cave and Karst Geoheritage Protected by UNESCO Protected Area Designation?	
10:15	Telbisz, Tamás	Karstic National Parks' Roles and Potentials - Views and Opinions from Tara National Park, Serbia	
10:30	Imecs, Zoltán	Karst Management in Apuseni Nature Park, Romania	
10:45	Fakin Bajec, Jasna	Landscape Perception and Traditional Knowledge for Sustainable Development of UNESCO Skocjan Caves Area, Slovenia	
11:00	Younes Arrad, Taha	Moroccan Caves and Their Implications in Scientific, Geoeucational and Geotouristic Programs through Speleological Activities	
11:15	BREAK		
	<b>CONCURRENT SESSIONS: CONSERVATION TOOLS</b>		<b>CONSERVATION SCIENCE</b>
11:45	Shackelford, Jennifer	Virtual Field Trips to Your Park - An Inexpensive Way to Reach the Masses	11:45 Čalić, Jelena Stripe Karst Tectonic Settings - examples from Eastern Serbia
12:00	Hildreth-Werker, Val	Cave Conservation and Restoration: Workshops Around the Globe	12:00 Olarinoe, Tunde A New Approach for Automatic Extraction of Karst Conduit and Matrix Recession Coefficients
12:15	Webb, Cathleen	The 2020 Mammoth Cave National Park Natural Resource Condition Assessment	12:15 Ford, Derek Mahony and Tunago, Adjoining but Contrasted Karst Plateaus in the NT, Canada
12:30	Holliday, Cory	Forest Management Considerations and Best Management Practices on Karst Landscapes: A Lesson in Evidence-Based Management Guidelines	12:30 Fryar, Alan Variable Responses of Mountainous Karst Springs to Seasonal Precipitation
12:45	Carlson, Justin	Middle to late Holocene Soil Geomorphological History at Crumps Cave and Sink, Potential Implications for Soil Conservation and Karst Terrains Today	12:45 Chamba, Bryan The first electrical resistivity tomography study applied to an Ecuadorian cave (Uctu Iji Changa, Tena): Insights into Amazonian karst systems
13:00	White, William	A Blueprint for the Assessment of Inorganic Carbon Flow Paths in the Great Onyx Groundwater Basin, Mammoth Cave National Park	13:00 Fandel, Chloe Representing Uncertainty with Diverse Model Ensembles: A Test Case in an Alpine Karst System
13:15	Meyer, Sonia	How Visitation is Affecting Air Quality in Carlsbad Cavern	13:15 Rasnake, Lindsey Characterizing Perennial Bedrock Springs in the Low-yield Aquifer Region of Southwest-Central Indiana
13:30	Addesso, Rosangela	Lampenflora, the alien of show caves: monitoring and treatments	13:30 Ponta, Gheorghe Monitoring Karst Aquifers in North Alabama for the Protection of Sensitive Aquatic Biota
WEDNESDAY, AUGUST 19		ALL TIMES IN CENTRAL DAYLIGHT SAVINGS (-5 HOURS GMT)	
7:30	Meeting Room and Virtual Help Desk Opens		
8:00	Gabrovsek, Franci	Environmental Monitoring in Skocjan Caves, Slovenia	
8:10	Serena Liso, Isabella	Complexity and Fragility of Apulian Groundwater Resources	
8:20	Parise, Mario	Establishing a Geopark in the Alta Murgia (Apulia, southern Italy)	
8:30	Ruggieri, Rosario	Clean up the Dark: Karst and Cave Conservation Initiative of the Italian Speleological Society (SSI)	
8:40	Zorman, Tomaz	Skocjan Cave - The cave and the paths of its explorers. Reflection of speleology in Classical Karst (Film)	
8:50	Van Beynen, Philip	The Economic Value of Florida's Groundwater	
9:00	Gani, Nahid	Investigating Geologic Controls of Western Pennyroyal Karst Region, Kentucky	
9:10	Williams, Jessica	In-cave Dye Tracing in Great Onyx Cave, Mammoth Cave National Park	
9:20	Gessert, Alena	Geotourism and Local Development in NP Slovak Karst: Behaviour Survey of Local People, Tourists and Experts	
9:30	BREAK		
10:00	<b>Concurrent Field Trips</b>		
	Karst Hydrogeology of Mammoth Cave National Park, Chris Groves, Will and Bette White, and Art and Peg Palmer		
	Archaeology and Cultural Resource Management at Mammoth Cave, George Crothers and Ed Jaikatus		
11:00	BREAK		
11:30	<b>Concurrent Field Trips</b>		
	Urban Karst Challenges: A Remediation Success Story, Pat Kambesis		
	Mammoth Cave Ecology, Kurt Helf, Rick Olson, Rick Toomey		
12:30	Meeting concludes for the day.		
THURSDAY, AUGUST 20			
7:30	Meeting Room and Virtual Help Desk Opens		
8:00	Concurrent Workshops		
	Exploring Best Practices in Data Management, Integration, and Visualization - Sarah Arpin and Pat Kambesis		
	Significance of Cultural Heritage in Karst Management: 2030 Agenda for Sustainable Development- Darja Kranjc and Jasna Bajec		
	GAZING DEEPLY: The Art and Science of Mammoth Cave - Tiffany Isselhardt and Chris Groves		
9:30	BREAK		
10:00	Concurrent Workshops		
	Citizen Science, Research and Land Management in Karst - Ben Tobin		
	CaveMAB- Lee Anne Bledsoe and Clayton Lino		
	Teaching Karst Through Environmental Education - Jennifer Shackelford and Jeanine Huss		
	Tools and Techniques for Urban Karst Hydrology and Hazard Monitoring and Management - Jason Polk and Adam Shelley		
11:30	BREAK		
12:00	Wrap-up: Workshop synopsis reports from facilitators.		
13:00	Meeting Adjourns		



## **Conservation of Fragile Karst Resources**

**A Workshop on Sustainability and Community in support of UNESCO science programs**