Annotated Bibliography of Research at Kartchner Caverns (1990-2021)

Even before it was developed, Kartchner Caverns was a well-researched cave. The exploration of knowledge continues even now, 40 years after the cave's discovery. Below is a list of the published articles on Kartchner Caverns, with summaries. Many of the articles are behind a paywall, so are unavailable unless the authors are contacted directly. We hope you enjoy reading about the science that is being done at Kartchner Caverns. *With contributions by Ranger Dylan Dorey, Kartchner Caverns State Park*

Bates, M., 2018. Forensic Rockfall Dating at Kartchner Caverns (Doctoral dissertation, The University of Arizona).

> An exploration of techniques available to date rockfall and assess the current weathering of rock surfaces in the cave. Rockfall can occur not only because of the geomechanics of faults and joints but can also be affected by the cave environment itself, such as through microbial action and chemical processes.

Bates, M., Kemeny, J., Wu, H. and Chen, N., 2016, June. Collecting Discontinuity Data at Kartchner Caverns Using LiDAR for the Purpose of Numerical Modeling. In 50th US Rock Mechanics/Geomechanics Symposium. American Rock Mechanics Association.

> In an effort to better understand the overall rock mass of Kartchner Caverns, LiDAR data was collected and inputted into a geomechanical numerical model. The overall trend of consistent short joints and small fractures was compared to single specific major faults and bedding planes. The interaction of these features with each other may be relevant to the overall stability of the cave system.

Billy, B., Budhu, M. and Casavant, R., An investigation of energy use, water, and wastewater treatment at Kartchner caverns state park, Arizona. Water/Energy Nexus. http://www.waterenergy.nau.edu/kartchner.html

> A discussion of how and where the park is getting its water. It goes over the supply, pumping, treatment, storage, and distribution of the water on park, as well as the wastewater treatment facility. It also determines gallons of water pumped per day as related to number of park visitors, and offers multiple suggestions for better efficiency and distribution so as to keep the water table at a sustainable level for as long as possible.

Blasch, K.W., 2011. Methodology to assess water presence on speleothems during periods of low precipitation, with implications for recharge sources-Kartchner Caverns, Arizona. *Journal of Cave and Karst Studies*, *73*(2), pp.63-74.

> Electrical-resistance sensors, temperature sensors, and groundwater levels were used to monitor the recharge of water into the cave from surface channel infiltration, overland infiltration from rainwater, and groundwater inflow, during a period of dryer than average weather over 4 years. During dry periods, there is almost a complete absence of recharge from surface channel infiltrations and a drastic decrease in overhead infiltration, which directly affects the wetness of cave formations. Despite the decrease in moisture levels on formations, the humidity level in the cave stayed the same.

Buecher, D.C. and Sidner, R.M., 1999. Bats of Kartchner Caverns State Park, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.102-107.

Baseline studies of the bat population and how that population affects the cave were conducted from 1989-1992. Nine different species of bats were recorded, including the Cave Myotis, or *Myotis velifer,* which use the cave as a maternity roost. The colony ranges from 1000-2000 bats which use the cave from middle of April to middle of September. Despite the possible limitation of use of the cave due to the possibility of predation, Kartchner Caverns remains an important and ideal roosting site for the bat colony. The bats also are important for the cave as well, as their guano is an integral part of the ecosystem and energy flows inside of the cave.

Buecher, R.H., 1999. Microclimate study of Kartchner caverns, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.108-120.

A two-year study of the microclimate environment inside of Kartchner Caverns, from 1989-1991, including the impact of the surface climate. Factors studied include: cave moisture levels, amount of water reaching the cave, evaporation rates, air and soil temperature, air exchange rate, and concentration of radon and carbon dioxide gases. The amount of moisture reaching the cave is barely adequate to maintain the humidity levels, so too much of a change in environment could cause the cave to dry out. The biggest threats to this (not factoring in tourism) include air exchange and temperature increase. Similar methods are in use today to monitor the health of Kartchner Caverns.

Buecher, R., 1990. Report on flooding in Kartchner Caverns. (internal report)

After observing extensive flooding in the back section of the cave, the author attempted to better understand the patterns of waterflow. Along with personal observations, other techniques employed were introduction of Flourescein dye at surface streams, activated charcoal packets left in possible high flow areas, and samples of water to test conductivity. After study, flooding of the back section of the cave is believed to happen more frequently than originally thought (perhaps once every few years), takes ~1-2 weeks to occur after surface rainfall, ad requires at least 6" of rain in the preceding month.

Carpenter, M.C. and Mead, J.I., 2003. Late Pleistocene roadrunner (Geococcyx) from Kartchner Caverns State Park, southeastern Arizona. *The Southwestern Naturalist*, *48*(3), pp.402-410.

The right femur bone of a Conklin's Roadrunner (*Geococcyx californianus conklingi*) was found in the Big Room. The fossil was dated at ~36ka and is the first reported evidence of the species in the state of Arizona. Comparisons of the specimen found it to be much larger than modern day examples and relatively larger than other comparable species found in other areas.

Cigna, A.A., 2001. Evaluation of the tourist impact in the Kartchner Caverns (Arizona, USA). In *Proc. 13th International Congress of Speleology* (Vol. 2, pp. 188-192).

Air, water, and soil temperature, humidity, and CO2 saturation levels were monitored at the various environmental monitoring stations throughout the cave, in order to determine the impact that tourism had on the environment. The most noteworthy change was in temperature, with each station showing a slow but steady increase in temperature, measured at about 0.2 degrees Celsius per year. The stations closest to the tour entrance tunnels saw the most and the quickest impact, with other stations further away showing less impact and a delay in showing those results.

Cigna, A.A., Pani, D. Quality assessment of show caves: the management evaluation index (MEI). In *16th International Congress Of Speleology* 2013 Jul 21 (p. 219).

The authors develop an index of how effectively show caves are managed for the dual purpose of conservation and profit. Using rankings from previous studies, and for access and pathways, visitors, surface, and cave environment, they rated 4 different show caves on their index. Kartchner Caverns, the beneficiary of learning from earlier cave development mistakes, received 94/100 points on the management evaluate index as of 2013.

Cole, J.E., Hlohowskyj, S., Vetter, L., King, J., Casavant, R.R., Woodhead, J.D., Drysdale, R., Truebe, S. and Henderson, G.M., 2017, December. A Continuous Holocene Record of Hydroclimate from Kartchner Cavern, AZ, Supported by Multiyear Dripwater Monitoring. In *AGU Fall Meeting Abstracts 2017.*

Through studying ratios of oxygen-18 isotopes in calcite speleothems, a 12,000 year history of monsoon precipitation was measured. It was determined that peak wetness of the monsoon occurred between 7000 and 9000 years ago. Between 2000 and 7000 years ago the data shows the monsoon starting to weaken, and the data shows no trend over the last 2000 years.

Davis, O.K., 1999. Pollen and other microfossils in Pleistocene speleothems, Kartchner Caverns, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.89-92.

In taking samples of speleothems for dating, pollen and other organic microfossils were found, albeit in low numbers. Most likely the pollen was washed in by water and remained on the formations, to be encased by calcite. Upon analysis of the pollen samples, it was found the species matched those that are currently found on the Colorado Plateau, while also containing agave spores that are currently found on park property. While the age of the pollen is indetermined, the age of the speleothems were between 76ka and 194ka. This suggests the climate at the time the pollen was brought in was more akin to that of the modern-day Colorado Plateau, which is cooler and wetter, but not too cool as to allow the agave to be present.

Espinasa, L., Pape, R.B., Henneberry, A. and Kinnear, C., 2012. A new species of Nicoletiidae (Insecta: Zygentoma) from Kartchner Caverns State Park, Arizona. *Journal of Cave and Karst Studies*, *74*(1), pp.82-89.

A new species, *Speleonycta anachoretes,* was discovered inside the cave. Fully grown specimens observed were between 10 and 15mm body length. It is believed their habitat tends to be confined to the periphery of the cave. They are currently the largest troglobite discovered in the cave. So far, human interference in the cave has not seemed to affect the population.

Ford, D.C. and Hill, C.A., 1999. Dating of speleothems in Kartchner Caverns, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.84-88.

Uranium series dating was performed on 30 different samples of speleothems in the cave, 19 of which yielded successful results, and the rest were deemed too "dirty" to give accurate results. The dates range between 40ka and 200ka, with the majority clustered around 70ka to 140ka, during the much wetter Sangamon time. A change in climate, most notably wetter to drier, was recorded in the crystalline structure of certain samples. Evidence of earthquake activity was also found in broken speleothems, as well as older hydrothermal activity found in quartz samples.

Graf, C.G., 1999. Hydrogeology of Kartchner Caverns State Park, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.59-67.

Hydrogeologic properties were studied for the three distinct systems that interact around Kartchner Caverns. Data was compiled from surface flows, soil moisture, water table depth, corrosion bevels, scallops, geophysical layout, and cave flooding observations, to determine the source of most of the water entering the cave, and the method by which it was entering. Water infiltrating from nearby runoff and washes and percolating water from above were the main source of water for the cave. It was also determined the cave has a 57% chance of flooding in any given year (as of 1999.)

Green, D.J., 2000. Discussion: "Geophysical studies at Kartchner Caverns State Park, Arizona". *J. Cave Karst Stud*, *62*(1), p.27.

The author disputes Lange's natural potential anomalies (Lange 1999) over Kartchner

Caverns, namely the observation that the rock above the cave is more permeable. The author states that the water should percolate down uniformly through the rock, not more rapidly over the cave. He states the NP anomalies are most likely real but there is no evidence to support they show more streaming potential. (For reply see Lange 2000.)

Hill, C.A., 1999. Mineralogy of Kartchner Caverns, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.73-78.

Kartchner Caverns has very diverse and significant examples of cave minerals. It exhibits minerals from 6 different classes: carbonates, nitrates, oxides, phosphates, silicates, and sulfates, some of which are rare, both in a cave setting or in geology in general. Several factors are responsible for such a diverse mineralogy, allowing Kartchner Caverns to exhibit multiple unique colors and crystal structures both in the speleothems and bedrock of the cave.

Hill, C.A., 1999. Overview of Kartchner Caverns, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.41-43.

Hill discusses the sequence of events comprising the formation and current status of Kartchner Caverns, starting with pre-cave events, beginning with the Mississippian period and the formation of the limestone, basin-and-range block faulting events, hydrothermal activity along fault lines, and alluvial valley filling, between 780ka and 320ma. Then she discusses shallow-phreatic events, including a stable higher water table and solutioning out of the cave, ~200ka. Finally, she outlines vadose events, including major speleothem growth and leading into human development, ~170ka to present.

Hill, C.A., 1999. Sedimentology and paleomagnetism of sediments, Kartchner Caverns, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.79-83.

Much of the cave floor is lined with clastic deposits, both coarse and fine grained. The older, fine-grained deposits consist of shattered fault gouge clay and silt, as well as blocky and unconsolidated clay, relating to the phreatic and faulting time period of cave formation. The younger, coarse-grained deposits include breakdown rock, pebble gravel, and micaceous sand, and relate to the vadose conditions of the cave. After paleomagnetic dating, the clastic layers are determined to be less than 780ka years old.

Holohan, B.C., 2009. Isolation and characterization of free-living nematodes and their trophic symbionts from Kartchner Caverns. Honors Thesis, University of Arizona.

Samples were taken from both inside the cave and from soil above in an attempt to identify various types of nematodes and their relationships with their corresponding microbes. It seems that most if not all found in the cave are bacterivores. Interestingly, not only did the various species differ between samples found inside the cave compared to outside, different species were also found between different environments inside the cave, such as samples taken from the guano and samples taken from the mud.

Ikner, L.A., Toomey, R.S., Nolan, G., Neilson, J.W., Pryor, B.M. and Maier, R.M., 2007. Culturable microbial diversity and the impact of tourism in Kartchner Caverns, Arizona. *Microbial ecology*, *53*(1), pp.30-42.

Samples of microbes were taken from cave rock surfaces in certain areas throughout the cave. Samples were taken from high impact areas (areas directly next to the tour trail, seeing 200,000+ visitors a year), medium impact areas (30-40 visitors a year), and low impact areas (2-3 visitors per year), and then compared, to determine the impact of tourism on the microbial communities of the cave. The high traffic areas showed a higher concentration of environmental bacteria, which was determined to be caused by higher levers of organic matter and lint from more visitation, with subsequently lower concentrations for each less visited area and slightly different microbial community structures in each location.

Jagnow, D.H., 1999. Geology of Kartchner Caverns State Park, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.49-58.

Detailed mapping of both the subsurface and surface geology of Kartchner Caverns and surrounding Whetstone mountain areas, including marker beds, faults and fractures, and type of rock. The cave was found to be entirely located in a down-dropped block of highly faulted Escabrosa Limestone. More than 60 faults were mapped cutting through the cave area, most likely caused by the movement of the block. 7 distinctly colored marker beds were also mapped inside of the cave, providing the key for unlocking both the subsurface and surface geology. Evidence inside the cave suggests that the cavern has been stable for at least 50,000 years, with certain areas having been stable for much longer.

Lange, A.L., 1999. Geophysical studies at Kartchner Caverns state park, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.68-72. Geophysical study conducted in 1989.

Three separate techniques were employed to map out the structure of the cave and groundwater patterns. Techniques used were electromagnetics, gravity, and natural potential. The electromagnetic survey was unable to detect voids in the bedrock but was able to distinguish between carbonate bedrock and valley fill. The gravity technique was able to detect voids and features of the bedrock and fault lines. The natural potential survey showed the most anomalies, and was able to map voids, underflow and percolation areas following the movement of water.

Lange, A.L., 2000. Reply: Geophysical studies at Kartchner caverns State Park, Arizona. *Journal of Cave and Karst Studies*, *62*(1), pp.28-29.

A reply to questions raised by Green (2000), defending the anomalies from the Natural Potential studies above the cave. Lange says the freefall of water from the cave ceiling to the cave floor, as opposed to the resistive pathway in solid rock, will show anomalies. He draws upon other's research to support his own findings.

Lange, A., Walen, P., and Buecher, R. H., 1990. Cave Mapping from the Surface at Kartchner Caverns State Park, Arizona.

Studies were conducted using electromagnetics, natural-potential surveys, and gravity surveys in an attempt to aid in the possible detection of other caves, to locate the best access site for the visitor entrance, and to map structure and groundwater below the park for siting of visitor facilities. This undertaking provided a useful guide for choosing locations of wells, structures, waste facilities and roads.

Legatzki, A., Ortiz, M., Neilson, J.W., Casavant, R.R., Palmer, M.W., Rasmussen, C., Pryor, B.M., Pierson III, L.S. and Maier, R.M., 2012. Factors influencing observed variations in the structure of bacterial communities on calcite formations in Kartchner Caverns, AZ, USA. *Geomicrobiology Journal*, *29*(5), pp.422-434.

After determining that bacterial colonies were unique and variable between formations, more research was conducted to determine what was causing this and how. The unique physical and chemical properties for each speleothem showed no correlation to the diversity of bacteria. What did show a correlation, however, was regional and relative location of formations, as well as differing drip pathways, possibly relating to different nutrients. It was determined that more research was needed for a better understanding.

Legatzki, A., Ortiz, M., Neilson, J.W., Dominguez, S., Andersen, G.L., Toomey, R.S., Pryor, B.M., Pierson III, L.S. and Maier, R.M., 2011. Bacterial and archaeal community structure of two adjacent calcite speleothems in Kartchner Caverns, Arizona, USA. *Geomicrobiology Journal*, *28*(2), pp.99-117.

Microbial samples were taken from two speleothems, with the goal of better understanding how bacteria directly affect speleothem formation and secondary mineral deposits. Of the samples taken, even though the speleothems were adjacent to each other, the specific colonies from one stalactite were more similar to each other than to the adjacent sample on the other stalactite. Subtle differences were also found in the elemental composition of each sample, suggesting both bacterial colonies and geochemistry might be unique and specific for each speleothem.

Mann, S.L., Steidl, R.J. and Dalton, V.M., 2002. Effects of cave tours on breeding Myotis velifer. *The Journal of Wildlife Management*, 66(3), pp.618-624.

Before tours started, an experimental manipulative study was conducted to see how the maternal bat population would respond to the introduction of humans on cave tours. Three different factors were studied: Size of tour group, volume of tour group (talking), and light intensity/color. 4 different behavioral responses of the bats were measured in response to above stimuli: number of take offs, number of landings, vocalization, and activity level. The brighter the light and the more disruptive or close the tour group was, the more these behavior responses increased. Also, all behavioral responses increased as the maternity season progressed. Based on these data, it was decided not to run tours in the Big Room (maternity colony) side of Kartchner Caverns when opened to the public.

Mead, J. I. and Johnson, C. B., Late Pleistocene paleontology of Kartchner Caverns State Park, southeastern Arizona: preliminary assessments. (internal report)

Discussion of the preliminary assessment of faunal remains and fossils found inside of Kartchner Caverns within the sediment. Discoveries were numerous and diverse, with 34 different species found in every sediment from every room sampled. Kartchner Caverns has been deemed noteworthy because of the faunal richness and time depth of samples, holding a record of the local faunal community of the past 86,000 years.

Meader, N. and Cascabel Conservation Association and Lower San Pedro Watershed Alliance 2016. Geology and Hydrology of Kartchner Caverns and their Relationship to the Vigneto Development. https://cascabelconservation.org/kartchner-caverns/

A hydrological connection between the groundwater found in the Benson block, which is the water that would be pumped for the development of the Villages at Vigneto, and the groundwater found in the Kartchner block, where the cave is located, was found to possibly exist. As to how much of an impact would be seen on the cave, a better understanding and more research is required. Any impact from the development would have to be weighed against the impact both from climate change and from the park's use of water, and might be inconsequential compared to these other two more influential factors.

Neilson, J. and Maier, R., 2001. Analysis of Slime Deposits on Fiberglass Surfaces in Kartchner Caverns. (initial report)

After observing a clear slime on synthetic rock and other fiberglass surfaces in the cave, samples were taken in attempt to characterize the organism(s) responsible. Several types of mucoid bacteria were cultured and determined to be the cause of the slime. The same species of bacteria were found in other parts of the cave, but were not the predominant population as such in the slime areas. It is believed that the fiberglass or the paint applied to the fiberglass could possibly be an added food source for such bacteria, or the porous surface itself encourages microbial growth.

Ortiz, M., Legatzki, A., Neilson, J.W., Fryslie, B., Nelson, W.M., Wing, R.A., Soderlund, C.A., Pryor, B.M. and Maier, R.M., 2014. Making a living while starving in the dark: metagenomic insights into the energy dynamics of a carbonate cave. *The ISME journal*, *8*(2), pp.478-491.

A correlation but not a complete overlap was found between microbial communities on the surface and those found on speleothems. It is speculated that the microbes found in the cave originated from soil being washed in from the surface and the specific low-nutrient environmental conditions inside the cave selected for the more oligotropic-tending species, and these are partly sustained by contributions from bacteria.

Ortiz, M., Neilson, J.W., Nelson, W.M., Legatzki, A., Byrne, A., Yu, Y., Wing, R.A., Soderlund, C.A., Pryor, B.M., Pierson, L.S. and Maier, R.M., 2013. Profiling bacterial diversity and taxonomic composition on speleothem surfaces in Kartchner Caverns, AZ. *Microbial ecology*, *65*(2), pp.371-383.

Bacterial samples from ten different speleothem surfaces were taken to determine the diversity of bacteria in the cave. Results showed an average of 1,994 different classifications per speleothem. Each speleothem not only showed a rich diversity of bacteria in relation to themselves, but also to each other, showing that each particular community is very sensitive to subtle variations in environment and location.

Pape, R.B., 2013. Description and ecology of a new cavernicolous, arachnophilous thread-legged bug (Hemiptera: Reduviidae: Emesini) from Kartchner Caverns, Cochise County, Arizona. *Zootaxa*, *3670*(2), pp.137-156.

> During a cave invertebrate re-survey, a new species (known as *Phasmatocoris labyrinthicus*) was discovered, among others. It is a type of carnivorous, caverniculous, arachnophilous thread-legged bug. Average size of fully grown species observed were 11-12mm. They are believed to be low-humidity intolerant, thus troglobitic by default, considering outside the cave is an arid environment. They are uncommon in the cave, with regional dispersal, tending to be found around the entrance areas.

Pape, R. and O'Connor, B., 2014. Diversity and ecology of the macro-invertebrate fauna (Nemata and Arthropoda) of Kartchner Caverns, Cochise County, Arizona, United States of America. *Check List*, *10*, p.761.

> Two year study of the macro-invertebrates in the cave, conducted from 2009-2011, expanding on the original invertebrate study from 89-91. List of invertebrates was expanded to over 98 different invertebrates, 16 of which were entirely new to science. With the expansion of the list, Kartchner Caverns is now known to harbor the most species-rich macroinvertebrate colony of any cave in Arizona.

Phillips, Jr, D. A., 1993. Interpreting surface artifact scatters: an example from southeast Arizona. In *Papers presented in the 58th Annual Meeting Society for American Archaeology* 1993 Apr 15.

> A sample of over 34,000 artifacts from 7.6ha were taken from Kartchner Caverns, from 8 different subsites. It was determined these sites had a use history of at least 3,000 years. This study was also an experiment and learning opportunity employing the Voight Mesa approach of taking samples.

Roth, K., 2016. Time-Dependent Rock Failure at Kartchner Caverns, Arizona. Master's Thesis University of Arizona.

> Long term rock stability was tested using a variety of methods. The Escabrosa Limestone is highly faulted and made of both homogenous and heterogenous mixtures, making the long-term stability difficult to determine. It was determined the heterogenous structure is less susceptible to crack growth than the homogenous texture. Rock bridges were determined to fail along the more homogenous textures first, with breakdown occurring through the matrix adjoining the veins than along the veins themselves. A specific rock bridge is believed to have a time-to-failure estimate of 1200-65,000 years.

Toomey III, R.S. and Nolan, G., 2005. Environmental change at Kartchner Caverns: trying to separate natural and anthropogenic changes. *Connecting mountain islands and desert seas: Biodiversity and management of the Madrean Archipelago II. Proceedings RMRS-P-36, US Department of Agriculture, Forest Service, Rocky Mountain Research Station: Fort Collins, CO*, pp.264-270.

Baseline studies of the microclimate in the cave (started in 1989) are compared to current data, which have been continuously monitored since. The cave is showing a warming and drying trend over the first 6 years of being open to the public. By examining patterns of change, and comparing those patterns to regional datasets of surface temperatures, water tables, and similar caves in the same area, it was revealed that both development/human interference, as well as regional climate change, are to blame for the changes in cave environment. More research is required to determine which factor is the main contributor of impact. (As of 2020, temperatures and humidity have stabilized since the addition of daily microfogging with zero chlorine water to combat the moisture exported on the clothes of guests and guides.)

Travous, K.E. and Ream, J.P., 2001, July. Developing and managing an environmentally responsible tourist cave. In *Proc. 13th International Congress of Speleology* (Vol. 2, pp. 231-233).

An exploration of science and techniques used in the development of Kartchner Caverns as a show cave, and in mitigating the ongoing impact of tourism. Extensive scientific surveys of the specific cave environment were conducted, giving a baseline to monitor against, and factors such as dust, moisture, and algae control were implemented during and after the development process.

Truebe, S. and Webster, K. 2020. High-resolution measurements of cave air carbon dioxide in the context of 30 years of cave air data from Kartchner Caverns, Arizona. 2019 National Cave and Karst Management Symposium Proceedings, 7- 11 October 2019, Bristol, Virginia. National Speleological Society, Huntsville, Alabama, USA.

The authors explored variability in carbon dioxide concentrations in cave air throughout the caverns with a CO2-meter that samples every few minutes. Although usually pressure and temperature variability are presented as reasons for CO2 fluctuations in cave environments, driving cave breathing with the outside air, in Kartchner, it seems that wind is an important variable. Perhaps seasonally-varying atmospheric pressure and temperature set up unstable conditions that require wind as a perturbation to begin mixing of CO2 between the cave and outside environment.

Truebe, S.A., Cole, J., Lee, M., and Barnett, H. 2012. Reconciling speleothem sampling for paleoclimate research with cave conservation. *National Cave and Karst Management Symposium Proceedings 2011*: 149-153.

The authors tackled the ethical issue of destructive sampling from caves using prescreening stalagmites with small cores for U-Th date samples, making a replica and placing it in the Kartchner Caverns "grow area" to see if either microbial or mold growth would be an issue, and finally coring stalagmites to see if that was a possibility. The authors propose that with a combination of careful site selection, sampling techniques, creative new methods for speleothem replacement, and archiving of materials, cave conservation and paleoclimate reconstruction can be reconciled.

Tufts, R. and Tenen, G., 1999. Discovery and history of Kartchner caverns, Arizona. *Journal of Cave and Karst Studies*, *61*(2), pp.44-48.

A summary and chronology of the journey of Kartchner Caverns in becoming an Arizona State Park. The processes for discovery, acquisition by the State, development, and conservation were outlined in order to demonstrate the painstaking care and circuitous route that was taken to make the park what it is today. A final reiteration is made confirming the most interesting and important part of the story is the conservation of the cave, both throughout the development process and through the future management of the park and its assets.

Vaughan, M.J.S., 2012. Fungal Community Diversity and Structure from Cave Mineral Surfaces and Bat Guano in Kartchner Caverns, Arizona. PhD Dissertation, University of Arizona.

Three studies were conducted studying the fungal diversity levels from different areas of the cave. The first study was taken from different speleothems and found that location directly affected community structure. The second study described samples from both speleothems and the rock walls and found that speleothems supported a higher fungal diversity and richness. The third study was taken from piles of bat guano over the course of a year and found no significant difference in fungal communities between different times of year.

Vaughan, M.J., Maier, R.M. and Pryor, B.M., 2011. Fungal communities on speleothem surfaces in Kartchner Caverns, Arizona, USA. *International Journal of Speleology*, *40*(1), p.8.

Fungal samples from 15 different speleothems were taken and isolated. A previous fungal study revealed a relatively low genera diversity and a homogenous community throughout. This study, however, revealed a higher diversity of different types of fungus as well as a more heterogenous community. Fungal communities differed both by sample site and speleothem type. More research is needed to determine true richness of mycological diversity, but survey revealed 43 different classifications, which is estimated to be about half of actual diversity.

Vaughan, M.J., Nelson, W., Soderlund, C., Maier, R.M. and Pryor, B.M., 2015. Assessing fungal community structure from mineral surfaces in Kartchner Caverns using multiplexed 454 pyrosequencing. *Microbial ecology*, *70*(1), pp.175-187.

Findings of distribution and structure of fungal communities were assessed based on differing factors of possible causation. Samples were taken from speleothems and rock walls at various different points throughout the cave and were compared based on different environmental factors such as distance from the natural entrance, nutrient enrichment from drip water, temperature, and CO2 levels. A greater degree of species richness and diversity was found on speleothem samples over the rock wall samples, also on samples closest to the natural entrance. No significant difference was found relating to temperature, CO2, or nutrient levels. The results suggest the most critical factor to fungal community structure involves proximity to the natural entrance.

Walker, D. 2019. Algae Identification and Discussion (internal report prepared for Dr. Sarah Truebe, Cave Resource Manager).

A number of swab samples were taken of lampenflora (algae growing at artiffical cave lights) and analyzed. No algae were actually found in any sample, only cyanobacteria. The species with greatest biomass was *Chroococcidiopsis* (possibly *C. thermalis*). This cyanobacteria is considered a good choice to survive on Mars for initial colonizers. In two samples, rotifers were found, indicating that lampenflora in the cave represents at least 2 trophic levels. Discussion of techniques for eradicating these lampenflora was beyond the scope of the study.

Waltz, D.R., 2014. A Reproduction of Recent Climate of the Southwestern United States Produced from Cave Deposits at Kartchner Caverns, Arizona. Honors Thesis, University of Arizona.

By studying ratios of oxygen isotope ratios recorded in stalagmite calcite, the climate conditions of the area were reconstructed for the last 2700 years. Oxygen isotopes ratios change over time due to changing climatic factors such as air temperature and amount of water. This can be compared with the study of different layers of tree rings, also sampled within the same area. The data shows that the climate in the area has fluctuated in the past, with long periods of drought, some lasting as long as 300 years, alternating with wetter periods, lasting as long as 100 years. What has been confirmed is that water is not a stable resource in the area.

Welbourn, W.C., 1999. Invertebrate cave fauna of Kartchner caverns, Kartchner Caverns, Arizona. *Journal of Cave and Karst Studies, 61(2),* pp.93-101.

Survey was conducted between 1989 and 1991. 38 different invertebrate species were discovered. 4 troglobites, 19 troglophiles, 1 trogloxene, 12 accidentals, a guanophile, and an obligate parasite made up the species discovered. The most commonly occurring species was an arthropod, mites found in the guano. The guano left behind by the *Myotis velifer* bats directly supports most of the species found in the cave. (see more recent re-survey under articles by Pape, many of these cave ecology words have been updated).

Zhang, L., Vranckx, K., Janssens, K. and Sandrin, T.R., 2015. Use of MALDI-TOF mass spectrometry and a custom database to characterize bacteria indigenous to a unique cave environment (Kartchner Caverns, AZ, USA). *JoVE (Journal of Visualized Experiments)*, (95), p.e52064.

Fifteen diverse bacteria samples were taken from Kartchner Caverns and were used to demonstrate the use of MALDI-TOF mass spectrometry techniques. All 15 samples were accurately identified down to the species using this method, confirmed by using a follow-up technique, 16S rDNA sequencing.