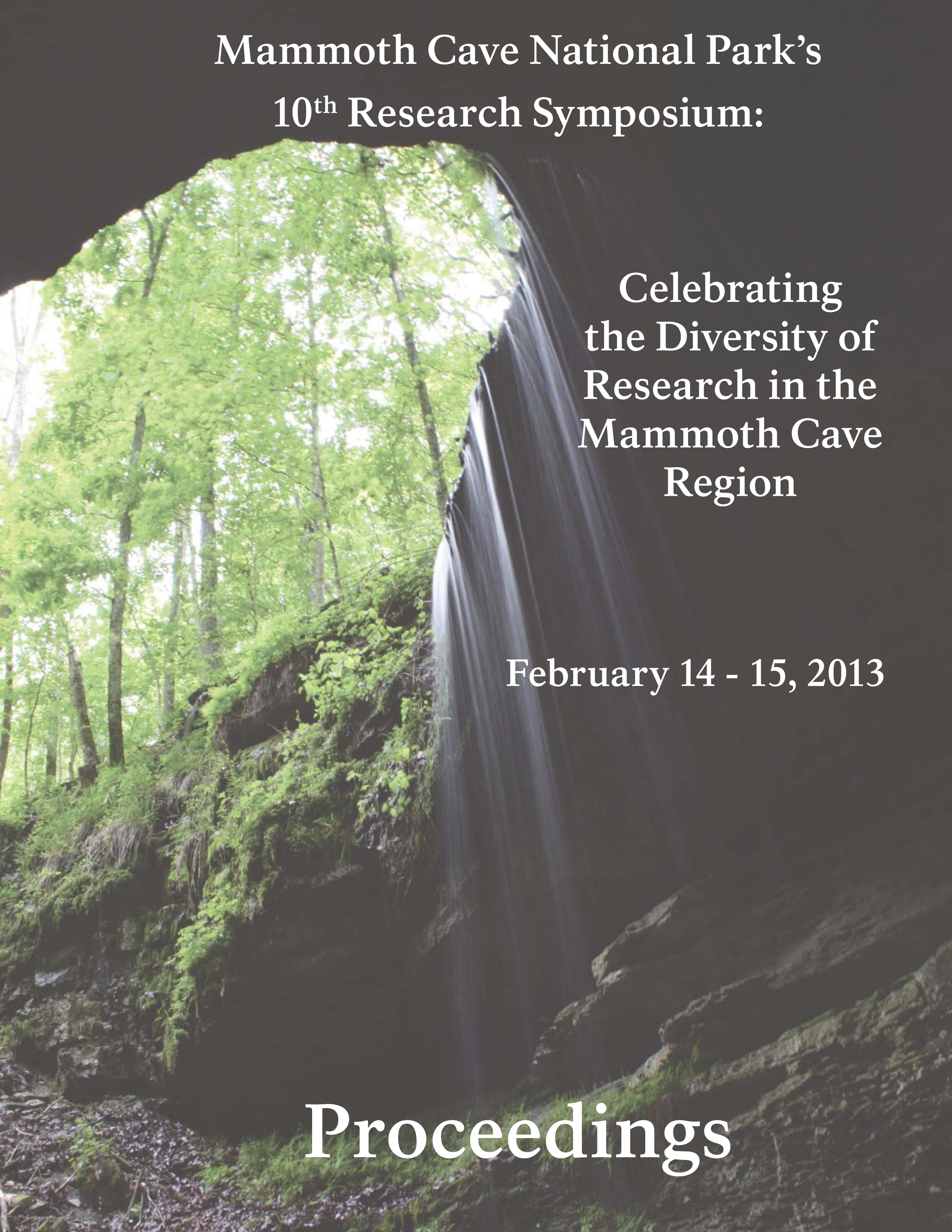
Mammoth Cave National Park's 10th Research Symposium:



Celebrating the Diversity of Research in the Mammoth Cave Region

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Proceedings

Mammoth Cave National Park's 10th Research Symposium: Celebrating the Diversity of Research in the Mammoth Cave Region

Biology and Ecology

Caving and Cave Survey

Geology and Hydrology

History and Archeology

Science Education and Interpretation

Resource Management

Assessing the Impact of Mercury Bioaccumulation in Mammoth Cave National Park

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Abstract

This project will examine the fate and transport of mercury in Mammoth Cave National Park, which has an extensive karst ecosystem. Contaminant transport in karst systems (limestone based surface geology) is rapid and extensive. Mercury's mobility in surface and ground water is of great concern due to its toxicity and ability to bio-magnify within food chains. However, mercury interacts with limestone, thus impairing its mobility. A number of federally listed species are declining in the parks. Further, Kentucky has issued a statewide mercury fish consumption advisory. With eight new coal-fired power plant applications under consideration in Kentucky, the potential exists for increased mercury deposition. Acquiring an understanding of mercury's bio-magnification through the food-chain, with an emphasis on federally listed species, will enhance NPS's ability to obtain emission reductions.

Ozone and Foliar Injury at Mammoth Cave National Park

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Abstract

Ozone is harmful to both visitors and plants in NPS units. The Cumberland Piedmont Network (CUPN) has been monitoring ozone and its associated foliar injury since 2008. The goal is to determine if ozone concentrations are high enough to cause injury to plants and whether that injury is actually occurring. Each year, ozone monitoring and foliar injury surveys are completed at two CUPN parks. Further, foliar injury surveys are completed every year at Mammoth Cave NP (and ozone data are collected annually by the park and its partners). Summarized data from 2008 through 2012 will be presented. The relationship between ozone concentration and the severity/amount of foliar injury will be examined for all parks within the CUPN. Further, correlation and trend analysis of Mammoth Cave data will be discussed. This information is used for New Source Review, in the review of Prevention of Significant Deterioration of Air Quality permit applications.

Establishment of Long-term Forest Vegetation Monitoring Plots within Mammoth Cave National Park

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Abstract

Beginning in 2011, the Cumberland Piedmont Network (CUPN) of the National Park Service (NPS) in cooperation with NatureServe, began monitoring forested vegetation communities within all 14 network parks, including Mammoth Cave National Park (MACA). The primary objectives of this effort are to: detect meaningful changes in species composition and vegetation structure within each park's forested habitat and determine whether these changes are correlated with trends in "key stressors." Thus far, 16 permanent long-term monitoring plots have been established within MACA. An additional 16 plots will be established in 2013-2014. Within the permanent plots, data are collected on forest structure; tree health, growth, regeneration and mortality; herbaceous diversity and cover; coarse woody debris; invasive species; and eventually soil. Currently, some preliminary observations on forest condition can be made including key stressors such as invasive exotic species.

2011 Vegetation Map for Mammoth Cave National Park

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Abstract

An accuracy assessment on a 2009 Vegetation Map of Mammoth Cave National Park produced by University of Georgia indicated inadequate reliability. As well, there were significant polygon boundary errors and unclassified polygons left blank on the map. With pressing need for a vegetation map to support the park's Fire Management Plan (FMP), a derivative of the 2008 Landfire map was produced. Specifically, 24 categories were regrouped into 4 vegetation categories useful for the FMP. Barrens and Prairie Plantation categories were added as superimposed polygons, and the same approach was taken for both fire and storm-linked forest canopy gaps. Accuracy assessment data points were sampled on a random basis until the cumulative percent correct stabilized, indicating that the sample size was adequate. The final cumulative average for this map was 66% accurate, which will require enhanced field checking of prescribed fire plots. Funding will be sought for yet a new map.

Introduction

An accuracy assessment by NatureServe (Smart and White 2010) on the 2009 Vegetation Map of Mammoth Cave National Park produced by the University of Georgia (Jordan and Madden 2010) indicated a percent accuracy far below the minimum 80% standard. With the pressing need for a vegetation map to support fire management in the park, a vegetation category consolidation strategy was developed by Olson, who then worked with Scoggins to achieve this in the GIS. Generalizing the map improved the accuracy assessment somewhat, but there were still significant problems. The accuracy assessment was based upon field data taken at random points in the park, which could inform whether the polygon was correct at that point, but which could not evaluate the whole polygon. Therefore, Olson carried out an assessment of polygon boundaries, which determined that there were many significant errors in boundary delineation between vegetation types. As well, it was discovered that there were many polygons never classified and simply left blank. Presentations of the residual errors were given to key park staff, and gradually the scope of the problem was realized. Acting Science and Resources Management Chief Tim Pinion organized a meeting with park and Natchez Trace fire management staff. After extensive discussions, it was accepted that a new map would be needed. There was urgency because revision of the park's Fire Management Plan (FMP) was already under way.

Alternate strategies for deriving a map were pursued. A proposal to acquire and classify multispectral Lansat data was prepared by Toomey and Olson because this approach worked well for a previous vegetation map of the park (Olson et al 2000). However, Burton suggested that the Nature Conservancy's Landfire map (LANDFIRE 1.1.0 Existing Vegetation Type Layer) might be sufficient, and so this was the avenue selected as the way to derive a sufficiently accurate and up to date vegetation map of the park in a compressed time frame, and with no funding.

Burton made the 2005 Landfire map available to Scoggins, who printed it out for review by Olson. Subsequently, we became aware of a more recent version produced in 2008. Scoggins procured the newer Landfire map from their website for use as data upon which to build a map to meet our needs. Based upon Olson's review of the 2005 map, which was very similar, he wrote a three page "Prescription for Altering the 2008 LANDFIRE Vegetation Map for Mammoth Cave National Park's Fire Management Plan".

Methods

Using the prescription as a guide, the following actions were taken to consolidate vegetation types meaningful for fire management planning. Several of the vegetation categories had low pixel counts, and these categories were individually displayed in a bright color to make them easier to find on the computer display. These sets of pixels were compared to adjacent vegetation and also with digital aerial photographs taken along with the LiDAR imaging. For vegetation categories with high pixel counts, we were able to find accuracy assessment points (Smart and White 2010) solidly within that category and look up field data on vegetation composition. With these comparisons as a guide, 24 of the 25 categories designated on the 2008 Landfire map were regrouped into 4 vegetation categories useful for the FMP. One Landfire category, South-Central Interior/Upper Coastal Plain Wet Flatwoods, could not be found and so was not reclassified. Barrens and Prairie Plantation categories were added as superimposed polygons, and the same approach was taken for both fire and storm-linked forest canopy gaps.

Results and Discussion

Four Landfire categories were consolidated into Xeric-Mesic Oak Forest/Woodland, which were: Southern Interior Low Plateau Dry-Mesic Oak Forest, South-Central Interior/Upper Coastal Plain Flatwoods, Central Interior Highlands Dry Acidic Glade and Barrens, and Central Interior Highlands Calcareous Glade and Barrens. These last two categories sounded promising, but turned out to be pixels scattered along roads and other apparently random locations. Representative species of the Xeric-Mesic Oak Forest/Woodland group are shown in red in Table 1 because this is a fire-adapted or fire tolerant community. It should be noted that the park does have dry limestone outcrop communities that have never been differentiated by any remote sensing mapping effort or by aerial photo interpretation. These communities, which have been called Cedar-Oak Glades and Cedar-Blue Ash Woodlands by different botanists, are very special communities. Several have been mapped by GPS circumnavigation, and that or high resolution habitat modeling will likely be needed to get these communities mapped in. We know where they are in each burn unit and can take their low fire intensity and frequency into consideration during the planning process.

Five Landfire map categories were consolidated into Mesic Hollow/Floodplain Forest, which were: South-Central Interior Mesophytic Forest, Central Interior and Appalachian Floodplain Systems, Central Interior and Appalachian Riparian Systems, Gulf and Atlantic Coastal Plain Floodplain Systems, and Central Interior and Appalachian Swamp Systems. Representative species of the Mesic Hollow/Floodplain Forest are shown in blue in Table 1 because this is a not a fire-adapted or fire tolerant community.

Two Landfire map categories were consolidated into Coniferous/Deciduous Successional Forest, which were: Ruderal Forest-Northern and Central Hardwood and Conifer, plus Southern Appalachian Low-Elevation Pine Forest. Based upon a vegetation map by Ivan Ellsworth (1936), a significant portion of the park was open or recently abandoned fields and pastures during the period of land acquisition for park establishment. On limestone substrate, these open areas tended to be dominated by Eastern red cedar, and on sandstone the old fields tended to be dominated by Virginia pine. With time, deciduous trees have become established too, but many of these species are not fire adapted and so great care must be taken if prescribed fire is used in these community types. Representative species are shown in green in Table 1 because few are fire-adapted or fire tolerant.

Thirteen Landfire map categories were consolidated into Disturbed Lands, which were: Developed-Open Space, Developed-Low Intensity, Developed-Medium Intensity, Developed-High Intensity, Barren, Agriculture-Pasture and Hay, Agriculture-Cultivated Crops and Irrigated Agriculture, Introduced Upland Vegetation-Treed, Managed Tree Plantation-Southeast Conifer and Hardwood Plantation Group, Managed Tree Plantation-Northern and Central Hardwood and Conifer Plantation Group, Ruderal Forest-Southeast Hardwood and Conifer, Bluegrass Savanna and Woodland, and Pennyroyal Karst Plain Prairie and Barrens. This last category was intriguing, but it consisted of a scattering of 18 pixels that were found to fall on open fields. Fire is not welcome in developed areas or farm fields, and so the vegetation examples are shown in green in Table 1.

The park does have Barrens or prairie community types on the Pennyroyal Karst Plain and equivalent karst valley habitat that was either present at the time of acquisition, such as Wondering Woods north of Chaumont, or which was released by deliberate removal of

Table 1: Community vegetation types, representative species, and coverage in the park. Due to the low precision inherent in mapping large areas with complex vegetation, acreages /percentages have been rounded. Red and bold indicates fire adapted vegetation, blue and underlined indicates non-fire adapted vegetation, and green in italics indicates where fire is not welcome such as developed areas, or where caution must be exercised in determining if fire can help move successional vegetation toward desired future conditions.

Vegetation Type	Typical Species	Acres/Percent of Park
Xeric-Mesic Oak Forest Woodland	**Chestnut, post, chinquapin, blackjack, black, and white oak**	22,300 acres / 42%
Barrens	**Prairie grasses, forbs, plus shingle, post, and blackjack oak**	120 acres / 0.2%
Prairie Plantation	**Prairie grasses and forbs**	110 acres / 0.2%
Mesic Hollow/Floodplain Forest	Sugar maple, beech, tulip poplar, box elder, sycamore	17,100 acres / 32%
Coniferous/deciduous successional forest	*Eastern red cedar , Virginia pine, red maple, tulip poplar, dogwood, sweetgum*	8130 acres / 15%
Disturbed lands	*Developed areas in fescue, road sides*	150 acres / 0.3%
Forest canopy gap – storm linked	*Downed pines, early successional and invasive plants.*	800 acres / 2%
Forest canopy gap – fire linked	*Downed and standing dead pines, successional and invasive plants.*	4120 acres / 8%

coniferous vegetation thickets so the seeds already in the soil could germinate, as on the Barrens south of Chaumont. None of the Landfire categories corresponded to these grasslands, and so polygons of actual Barrens communities were superimposed upon the map. The park also has three locations where prairie grasses and forbs have been planted in disturbed areas. These plantations show no evidence of having been natural prairie or barrens, and simply serve as refuges for marginalized species. The Prairie Plantation polygons can be found at the former Job Corps Center on Flint Ridge, the current Job Corps Center (called Eagle Prairie), and at the site of the former Great Onyx Hotel (called Onyx Meadows). Both restored and installed grasslands require frequent fire for maintenance, and so the characteristic vegetation is shown in red in Table 1.

Two classes of forest canopy gaps were mapped using different data sets. Storm-linked canopy gaps were mapped using a GIS layer created by Toomey using a portion of LiDAR data on forest structure. These gaps are based upon vegetation 2 meters or shorter, and are mostly found in Virginia pine stands damaged by an ice storm in January 2009, plus other less catastrophic storms. Fire-linked canopy gaps were based upon fire effects team field observations for development of composite burn index (CBI) data. This groundwork was used in conjunction with remote sensed data to generate burn severity maps. These maps are provided with the caveat that they are intended for use on a broad scale. However, the two burn severity pixel categories indicating the hottest areas were highly correlated to canopy gaps shown with Toomey's LiDAR layer, indicating high spatial accuracy. We know that these areas with high burn severity have standing dead Virginia pines and Eastern red cedar killed by fire. This makes these canopy gaps quite different from the gaps caused by storm damage only. Both types of canopy gaps can be virtually visited via Google Earth aerial photographs of the park where downed and standing dead trees can be seen. Field observations will be needed to determine current vegetation and if, when, and how prescribed fire may be useful in moving these gaps toward desired future conditions.

Accuracy Assessment

In late March of 2012, Scoggins set up Olson on the GIS over a period of four days to do an accuracy assessment of this vegetation map derived from the 2008 Landfire Map and also the 1999 Satellite Vegetation Map based upon 1995 Landsat multispectral imaging. Both maps are based upon Landsat imagery.

Based upon blocks of 50 accuracy assessment points chosen by a Stat Trek random numbers table from the NatureServe data set, the percentages of points correct for the derivative Landfire map were 64%, 54%, 78%, and 70% with cumulative accuracies coming in at 59%, 65% and finally 66% with all 200 points. This does not meet the national standard of 80% minimum correct, but given that we desperately need a vegetation map for the prescribed fire program, we can still use it by doing more field checking in burn units, especially for developing ignition maps.

The 1999 Satellite Vegetation Map map did not fare quite so well. Again, based upon the same blocks of 50 accuracy assessment points chosen by the Stat Trek random numbers table from the NatureServe data set, the percents correct for this map were 50%, 44%, 66%, and 46% with cumulative accuracies coming in at 47%, 53% and finally 52% with all 200 points. This map is old and it also has more vegetation categories, which increases the chance of being wrong.

Thankfully, in both cases the cumulative percentages stabilized within one percentage point, indicating that the sample of 200 was adequate.

Conclusion

There are aspects of this map that offer more information than the 2000 vegetation map of the park. For instance, canopy gaps caused by storms or fire are delineated, and these will be useful for fuels classification and for determining some nodes of exotic plant invasions. On the other hand, successional vegetation is lumped into one category in the current map, and this precludes learning anything about spatial changes in successional status. The 2000 map has three categories of successional vegetation, which can inform the trajectory at different sites. For this reason alone, it is worth acquiring Landsat data in the future and classifying it as we did for the 2000 map so that we can compare "apples to apples" with approximately two decades between Landsat datasets.

There are exciting possibilities for the future. Toomey has indicated that it should be possible to derive a DEM of the vegetation surface and then drape the classification on top of that surface, which could really help us better understand vegetation structure. As well, Burton pointed out that Cecil Frost's studies on pre-settlement vegetation will help inform us in determining desired future conditions in different habitat types in the park, and that these data can be used in future vegetation mapping efforts.

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Fire Regimes, Buffalo and the Presettlement Landscape of Mammoth Cave National Park

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Abstract

The glory of the caves has long overshadowed other features of the park but the neglected upland landscape has its own extraordinary tale to tell. The park occupies a naturally fire sheltered setting in a historically vast fire landscape of barrens and woodlands once populated by Native Americans, bison and elk. The events aboveground, spanning several thousand years before the arrival of Europeans and the subsequent explosive transformation of the land add rich layers of natural and human history, sadly neglected in development and interpretation of the park. This is the tale of the Barrens region itself.

We constructed maps of historical fire frequency and vegetation, using 2,681 witness trees compiled from original land surveys beginning in 1781. Original fire frequency was interpreted using tree species and the degree of fire exposure of each tree in the landscape, e.g. fire exposed ridgetops, slopes or grassy barrens versus fire sheltered lower slopes, hollows and bottoms. The topographical setting was examined for characteristics related to fire spread such as pathways for fire flow, natural firebreaks and the size of fire compartments. The natural fire relations of each tree species and its distribution on the land were used to assign fire frequency to each site and region. Original fire regimes were complex and extreme: fire frequency ranged from nearly annual fire in the true prairies and grassy woodlands on the limestone karst plain to the south – and on the plain between the Dripping Springs Escarpment and the Green River – to strongly fire sheltered hollows and bottoms within the park. The most fire sheltered sites were defined by the deep limestone bowls developed by karst topography – formed by millennia of dissolution of limestone by subterranean waters – and the rugged relief provided by the deeply entrenched Green and Nolin Rivers.

Introduction

The distribution and fire relations of trees found on the earliest surveys provide a new view of the Mammoth Cave landscape with tantalizing evidence concerning the return of bison to Kentucky in pre-Columbian times and circumstantial evidence for earlier introduction of European disease before DeSoto.

With postglacial warming, the large Pleistocene mammals of Kentucky, documented as fossils in the mires of Big Bone Lick, either migrated north, as with moose and caribou, or became extinct. Seven of the extinct species, however (American mastodon, Columbian mammoth, Jefferson's ground sloth, Harlan's ground sloth, complex-toothed horse, elk-moose and helmeted musk ox), should have had no trouble following the sub-boreal habitat as it moved north with the melting ice. All, however, vanished between 10,000 and 12,000 years ago, coinciding somewhat precisely with arrival of the earliest Clovis hunters in the region around 10,000-11,500 years ago and Clovis spear points occur in sediments of that age at Big Bone Lick (Hedeen 2008). Never in their evolutionary history had any of these animals experienced humans and the slow-moving ground sloths must have been easy pickings for well-armed, smart hunters. No other plausible reason has been advanced for the sudden disappearance of these mobile animals who had evolved in this landscape for hundreds of thousands to millions of years.

Other native species such as *Bison bison* antiquus, were also extirpated during this era but persisted in the sparsely populated West to give rise to the modern species. The reason for return of their descendants, *Bison bison*, to Kentucky, after a hiatus of nearly 10,000 years, and before the supposed date of introduction of european diseases is an unanswered question that looms large.

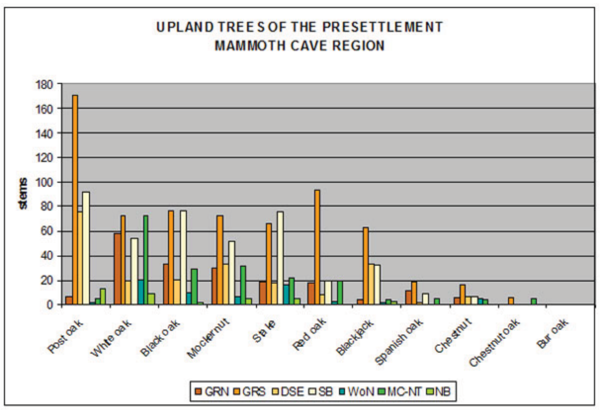

Figure 1: Upland Trees in the Presettlement Mammoth Cave Region. The most abundant tree of 2,681 original surveyors' witness trees found in and around Mammoth Cave National Park was post oak. This seems startling in view of the sparse distribution of the tree today, but post oak is a fire dependent species; it was once dominant on the side slopes and edges of the nearly treeless prairies to the south and north of the park – the "Barrens" – and on the more fire exposed ridges within the park, especially on the south side of the Green River. Region codes: GRN – Green River North side, GRS – Green River South side, DSE – Dripping Springs Escarpment zone, SB – Southern Barrens, WoN – West of Nolin River, MC-NT – Mammoth Cave-Northern Transition (between central MACA and the Nolin River north of the park), NB – the Northern Barrens north of the northern, west to east-trending section of the Nolin.

The beginnings of farming around 3000-6000 B.C. and development of a more complex tool kit including the bow and arrow in the Late Woodland Period (400-1000 A.D.) would have allowed the land to support increasing numbers of native peoples. With 10,000 years for equilibration, at each stage of evolving technology the land probably supported all the Indians that it could at that time. By around 400 A.D, at the end of the Late Woodland there were fully agricultural communities across Kentucky (Lewis 2006) and U.S. populations peaked at a still debated 1.8 to 18 million. The lower estimates may not take into account possible higher densities even before first extensive European contact through the Desoto expedition. DeSoto, who had "a privileged glimpse of an Indian world", described areas of the Southeast "thickly

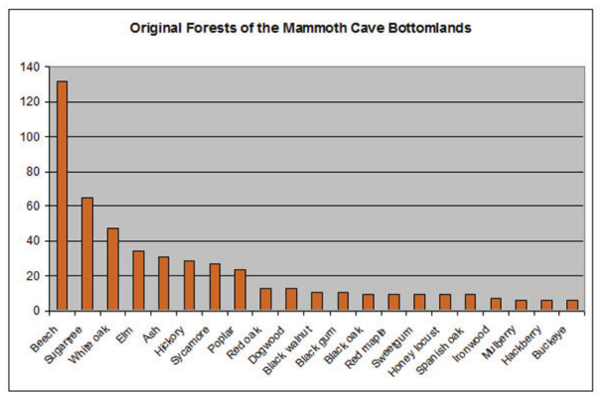

Figure 2: Original Forests of the Mammoth Cave Bottomlands. Fire-refugial beech and sugar maple – universally called "the sugartree" by early surveyors – dominated the deep hollows and bottomlands. Sugar maple supported a thriving cottage industry of maple sugar production for the first century, peaking at 34,000 pounds in the census year of 1840 (U.S. Censuses of Agriculture). Production thereafter declined decade by decade as bottomlands were cleared for farming and pasture and all of the old trees were eventually consumed by production of lumber and another cottage industry, sawed railroad ties that were shipped downstream (Warnell 2006).

Table 1: Presettlement Fire Regimes of the Mammoth Cave Region. Based on evidence from witness trees, topography and historical data, nine fire frequency classes could be distinguished at Mammoth Cave. These ranged from nearly annual fires in the vast flammable grasslands of the barrens, where a fire ignited several counties upwind to the southwest could potentially reach the Green River, to nearly fire-free pockets in deep hollows and on north facing slopes above the Green River firebreak. The last two columns show the calculated acreage in each fire frequency class in the park and an approximation of the mean annual acreage burned historically in each class.

Fire Freq. Class	Mean Fire Interval Years	Historic Range of Variation	Description	Acres	Acres Burned Annually
A	3	1-5	Karst plain & other barrens	1,226	408
B	4	2-6	Prairie-woodland mosaic	12,223	3,055
C	5	3-9	Pyrophytic woodland & karst depression communities	13,569	2,713
D	6	4-12	Oak-hickory woodland	11,128	1,854
E	8	5-20	Understory fires in forest	6,656	832
F	25	18-35+	Light fires in hardwood litter, to almost no fire in sheltered mesophytic forest	850	34
G	Infrequent	Variable	Steep, variably sheltered hardwood slopes	3,011	n.a.
H	Sheltered	Variable	Rare light fires in hardwood litter in alluvial bottoms	673	n.a
I	1-10	Variable -Anthropogenic	Heavily influenced by nearby resident Indians	1,158	variable
			Total acres	50,494	8,896

set with great towns". In 1682, more than a century later, LaSalle found the same areas deserted.

DeSoto visited the southern Cherokee villages and traveled west along a route to the south of the Cumberland River, as shown on the De L'Isle map of 1718, which includes Kentucky & Tennessee. The epic expedition provided opportunity to spread diseases throughout the region and it may be no coincidence that the Indians resident in Kentucky at the time, the Mississippian and Fort Ancient cultures, died out within the next century, 1540 to 1600, or 60 years in the case of the Mississippians, and 1540 to 1650, or 110 years for the Fort Ancient Indians).

Archeological knowledge of the Late Woodland period is still very sparse but sites from the Mississippian (the last culture in the Mammoth Cave region) and Fort Ancient and all earlier periods are scattered all across Kentucky (Lewis 1996). There is no reason why the second wave of explorers – French, then English – should have found an empty land other than it had been depopulated by diseases introduced 60 to 110 years before the last native cultures died out.

If elimination of the large food species was accomplished by the first wave of thinly distributed Paleoindian Clovis hunters, the increase in population density of later cultures with more highly evolved tools such as the bow and arrow, should have prevented the return of any large animals other than fast-breeding deer and small game. And yet bison returned from the west. One explanation suggests that relief from hunting pressure occasioned by decimation of modern Indian populations by European diseases allowed expansion of bison into the East. And yet the radiocarbon dates of modern bison bones at Big Bone Lick indicate their return to Kentucky by at least 1450, nearly a century before the presumed plagues introduced by DeSoto (Tankersley 1985).

The return of bison before Columbus suggests the possibility of an earlier introduction of disease than usually supposed. This may not be unreasonable since there had been temporary settlements along the northeast coast in the 1300s by northern European fishermen and there has been speculation of undocumented early exploration of the lower Mississippi. Other fishing boats may have been carried away by storms to introduce disease to the New World but never to return. Any such incursion could have introduced an earlier wave of disease, reducing Indian populations in at least some areas, bringing about sufficient release of bison from hunting to allow some to expand into the East. This is speculation, but offers a reasonable explanation and should prompt further research into early contact with the western world.

Though little studied, the barrens of Kentucky and Tennessee likely formed at the same time as the “prairie peninsula”, a woodland-forest-prairie mosaic that extended from Iowa east into Illinois, Indiana and Ohio (Transeau 1935). in the eastern U.S., peak post-glacial temperatures appear to have been reached during the Holocene Climatic Optimium or Hypsithermal period, some 4000-6000 years ago with temperatures perhaps 1 or 2 degrees C higher than at present. The warm peak should have occurred early in this period in the barrens area and moved to the Northeast with recession of the Laurentide ice sheet into Canada. Warmer temperature would have been accompanied by increased thunderstorm activity associated with the swirl of moisture that flows up from the Gulf of Mexico, the driver of lightning ignition regimes in the South and Midwest.

While Indian ignitions were dominant in specific regions (Frost 1998), they always occurred against a background of lightning ignitions and lightning is the ancient driver of fire regimes as well as the evolution of fire-dependent species, extending back hundreds of millions of years to the first evolution of land plants.

In the 1960s ecologists discovered fire, as E.V. Komarek published a pioneering series of articles in the Proceedings of the Tall Timbers Fire Ecology Conferences documenting the role of lightning in maintaining fire regimes in the South. In Florida in 1962 he tabulated 1146 lightning ignitions and 1048 in 1963 and that was only for some 2/3 of the counties reporting data (Komarek 1964). That rate should have been sufficient to fund a high fire frequency even with no contribution by Indians. Lightning alone, millions of years before North America saw its first human, would have accounted for evolution of the many fire dependent species of the South, including post oak and prairie coneflower found at Mammoth Cave.

Indian uses of fire have been well documented and some have theorized that since Indians used fire, Native American burning accounts for the presettlement fire regimes of the U.S. Others have extrapolated this idea far enough out on a limb to claim that the barrens and other eastern grasslands were created immediately before settlement in the 1700s, driven by Indian use of fire to promote habitat for buffalo so they could be hunted for skins to trade to the Europeans! Even rudimentary knowledge of the role of lightning ignitions, original fuels and the role of topography in regulating fire frequency renders this supposition insupportable.

1) Fire compartment size drives fire frequency regardless of whether Indians or lightning did the igniting. The barrens to the north and south of Mammoth Cave are comprised of thousand square mile compartments, originally covered with a mosaic of mid-grass and eastern tallgrass prairie, as well as grassy post oak savannas, all with flashy fuels, the ignitibility, flammability and fuel connectivity of which have no counterpart today. This explains why the thunderstorms of today rarely ignite wildfires and those that do rarely burn more than an acre, instead of tens of thousands of acres. The probability of ignition in a natural grass landscape is many times higher than in the modern mosaic of forest leaf litter, tilled fields and overgrazed pasture.

2) The natural fire flow stopped around 1830 as numbers of domestic livestock on open range approached saturation, eliminating grass fuel connectivity.

3) The historical dominance of the tree flora by fire dependent species such as post oak and blackjack, and the fire refugial distribution of fire sensitive trees such as beech and sugar maple on the original surveys refute any idea of recent creation. The distribution of dominant trees reported by the early surveyors could not have been produced by introducing fire 50, 100 or even 500 years before English settlement. None of the dominants were weedy species and even if planted by hand, carefully placing the beech seedlings in the hollows and the post oak, blackjack and mockernut hickory on the fire exposed upper slopes and ridges, it would take 300 years for the hypothetical forest to develop to the sizes reported at first settlement. Without meticulous human control a fire-mediated tree distribution should take thousands of years to develop under a natural fire regime whether Indians or lightning provided the ignition. Similarly, the species richness of the grass-forb layer, including many species endemic to southeastern prairies and savannas found in small remnants today would have required thousands of years for assembly.

The first French explorers and later Virginian and Carolinian long hunters found extensive grassland in the barrens and in the bluegrass region. It is striking that, even without Indians, the barrens were maintained in grass and largely free of trees for 240 years, from the time of DeSoto's passage and depopulation of Indians, until the land was opened for settlement in 1780. The Mississippian Indians were wiped out by 1600, within 60 years of the passage, removing any influence of resident Indians for at least 180 years before opening of the barrens to settlement. Indians undoubtedly added to fire frequency before their decimation but the fire regime that persisted follows a pattern compatible with lightning ignition, undisturbed grassy fuels and large fire compartment size, not dependent upon Indian ignition.

After depopulation the barrens were far removed from remnant bands of Indians—the Cherokee in the mountains of NC, the Shawnee in southern Ohio and the Chickasaw to the south in Tennessee and Alabama. Before the tribes obtained horses, just a short time before settlement, any long distance travel was by foot and there was no convenient way for overland transport of hundreds of pounds of meat from even a single buffalo. The Green River, called the Buffalo River by the French, provided the only route for canoe transport, leading west only to the towns of the Iroquois across the Ohio river from its mouth where buffalo were already conveniently located.

The maintenance for at least 180 years of vast areas of grassy barrens described by the first settlers cannot be ascribed to a small number of Indians on raiding expeditions or hypothetical seasonal hunters who traveled on foot to hunt big game that they could not transport and there is no evidence to support widespread burning after extirpation of the resident tribes. That leaves the ancient lightning fire regime to explain the landscape found by the first explorers.

The settlers also used fire widely but the barrens fire regime collapsed with a few decades after settlement in spite of that.

Lightning

Our ignorance of historical lightning ignition rates and of fire-maintained grasslands in the Southeast has been underscored by Reed Noss in his new book "Forgotten Grasslands" (2013). The Mammoth Cave region has a lightning strike density of 4-8 strikes per square kilometers per year (NOAA/National Weather Service). For Mammoth Cave, which occupies some 50,494 acres or 205 square kilometers, that gives 820-1640 lighting strikes per year. In the grassy landscape that surrounded and interpenetrated the park along the ridges south of the river, that should have been enough to produce abundant fire. The conditions that perpetuated the barrens after 1540 finally came to an end some 180 years ago, within five decades of settlement, when the original fire regimes died around 1830.

Transformation

After 1779 the Virginia legislature appointed commissioners to determine the validity of claims for land on the frontier and by April 1780, the commissioners approved more than 1,300 settlements and preemption claims in Kentucky. This opened the door for the largest land rush in Kentucky history, the state was flooded by settlers, investors and land speculators. Henderson was the entry point for settlers coming up the Green River into the Mammoth Cave area and by November 1780 over 5000 claims had been entered in the surveyor's office at Wilson Station near what is now Henderson at the mouth of the Green River on the Ohio.

Settlers swarmed in, first establishing homesteads in the barrens, and along both sides of the Green River at Mammoth Cave, a region where Indians were seldom seen. While settlers were infiltrating these lands, colonists in the Bluegrass region to the north were engaged in an all-out, seven-year war for Kentucky, 1775-1782, a struggle with the Ohio Shawnee, the only tribe offering substantial resistance. At its height the Shawnee destroyed the corn crops and settlers faced starvation, whereupon, the native grazers, elk and bison, were extirpated (eaten) during a single decade, 1775-1785, leaving only a few survivors to persist for a few more years. The last confirmed reports of wild buffalo in the state came from Hart County not far from the park, where a few were seen going down to the Green River as late as 1820 (Kleber 1992).

Settlement initiated a cascade of land changes that extinguished the complex natural fire regime throughout Kentucky over a 50 year period 1780-1830. For the first three decades 1780-1810, settlers writing home reported an easy life, subsisting on game and livestock that thrived on huge tracts of open range grassland and woodland, supplemented by small plantations of corn (Loving 1812). After 1810 increasing population density drove the shift to increasing dependence on agriculture; travelers in the 1840s on the way to the "wilderness" of Mammoth Cave were at first disappointed with the thoroughly agricultural nature of the land between Bowling Green and the Dripping Springs.

Domestic livestock proliferated on open range, with sustainable numbers exceeded by around 1930, and severe oversaturation by 1850 (Figure 4). Fire flow was disrupted by roads and plowed fields but especially by saturation of the landscape by hordes of livestock which consumed the grass fuel required for fire spread. With the end of fire, post oak, blackjack, black oak

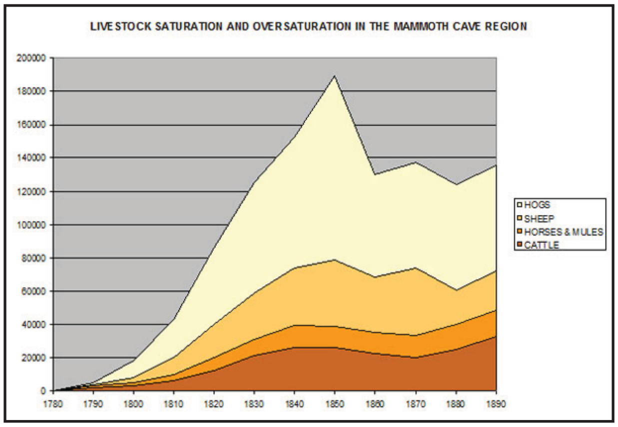

Figure 3: Livestock Saturation and Oversaturation at Mammoth Cave. Beginning in 1840 livestock were censused along with people. Prior to that we know that, with exception of an occasional party of long hunters with horses, or the rare backwoodsman who attempted to set up an early homestead in spite of Indians, there were essentially no domestic livestock in the region before 1780. The intervening decades up through 1830 are estimates. The picture is typical of the pattern of livestock introduction: Malthusian increase with unrestrained exploitation of open range, until reaching terminal supersaturation and subsequent dieback to a relatively stable asymptotic plateau. This picture is seen repeatedly throughout the South with the supersaturation peak reached in the 1700's in coastal Virginia, and coastal Alabama, 1840 in central Mississippi, Georgia and Alabama and 1850 in Kentucky and Tennessee. The rolling wave continued westward with the advancing frontier, peaking in the western Great Plains and midgrass prairie of Montana around 1905. At Mammoth Cave the original fire regime died around 1830 upon saturation of the landscape with sheep, hogs, horses, mules and cattle, eliminating grass fuels sufficient to carry fire. By 1847 travelers reported the former barrens becoming overgrown with brush and blackjack.

and other species of slightly fire sheltered side slopes in the barrens spread onto the uplands. Woody succession in the absence of fire was so far advanced by 1847 that one contemporary traveler noted "…the Barrens, formerly an extensive prairie,[are] now overgrown with a scrubby oak called Black Jack."

Over the 166 years since 1847, the landscape has been increasingly fragmented by roads, towns, fields and overgrazed pastures with insufficient grass fuel to carry fire, to the extent that fire will never again reassert itself without human intervention. While the original fire regime has been dead for at least 180 years and some of its component plants and animals such as elk and buffalo extirpated, many fire dependent species are still hanging on, along sunny roadsides and in the few places that have been burned. National Parks are among the few places where this heritage can be preserved, where fire can be reestablished in its natural role where future generations can see windows into the original landscapes, with their diversity of grassy prairies, flowery post oak savannas and all the plant, animal and bird species dependent upon them for survival.

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Remote Sensing of Forest Trends at Mammoth Cave National Park from 2000 to 2011

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Abstract

The influence of climate change and other environmental stressors on the health of mid-latitude forests is an important, yet understudied topic for resource managers. Using vegetation indices derived from satellite remote sensing, slight changes in photosynthetic activity can be detected at the spatial scales needed for long-term forest monitoring. This study used remote sensing and geographic information systems to track the photosynthetic activity within Mammoth Cave National Park from 2000 to 2011. Relationships are examined between climate variables and the vegetation indices for the forest as a whole and at selected areas within the park.

Disjunct Eastern Hemlock Populations of The Central Hardwood Forests: Ancient Relicts or Recent Long Distance Dispersal Events?

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Abstract

Eastern hemlock (*Tsuga canadensis*) is an evergreen conifer with a contiguous distribution extending from the southern Appalachian Mountains north to Nova Scotia and west across the Great Lakes region. Eastern hemlock is threatened with extirpation from much of this range by an introduced pest, the hemlock woolly adelgid (Orwig et al. 2002). In addition to the contiguous distribution, many small, isolated populations are located within the central hardwood forest region of Kentucky, Indiana, and Ohio (Braun 1928, Potzger and Friesner 1937, Van Stockum 1979). These disjunct populations form clearly delineated, often monospecific stands associated with unique natural features such as north facing cliffs and box canyons (Hart and Shankman 2005). Disjunct populations have long been of interest to biologists and two primary hypotheses for their origin have been proposed: 1) They are the product of rare long distance dispersal events (Gamache et al. 2003, Nathan 2006), or, 2) Remnants of what was once a portion of the contiguous distribution (Daubenmire 1931, Richardson et al. 2002). If long distance dispersal was responsible for the formation of these populations, we predict the resulting genetic bottlenecks to result in low within-population diversity, a correlation by distance to source populations and large between-population differences. Conversely, if these populations represent post-glacial relicts, we predict within-population diversity to be dependent on population size, no correlation by distance to source populations, and low between-population differences.

To evaluate these hypotheses we amplified microsatellite loci from DNA samples of 480 trees located in 17 disjunct populations (including one in MCNP), and 7 reference populations in the contiguous distribution (Figure 1). Standard descriptive for molecular data were calculated, including allelic richness, identification of alleles unique to single populations, and observed and expected heterozygosity (H_o and H_e). Linear regression was used to assess correlations between genetic diversity and population size and distance to source populations. Nei's unbiased genetic distance (Nei 1978) was used to examine for between-population genetic differences.

Of the 21 published microsatellite primer pairs for eastern hemlock (Josserand et al. 2008, Shamblin et al. 2008) we found 15 that consistently amplified products in the expected size range, of which 14 were polymorphic. We chose seven of these to conduct our full survey. The number of alleles of each of these seven loci ranged from 4 to 23 with an average of 10.3. Mean allelic richness across all seven loci for each population ranged from 7.0 to 1.7, with a mean of 5.9 for reference populations and 3.1 for disjunct populations. Disjunct populations also displayed a lower level of observed heterozygosity than expected ($H_o = 0.27$, $H_e = 0.42$) compared to reference populations ($H_o = 0.60$, $H_e = 0.64$). Twelve alleles unique to single populations were identified, with eight located in disjunct populations and four in reference populations.

In disjunct populations, mean allelic richness of populations did increase significantly with population size (Figure

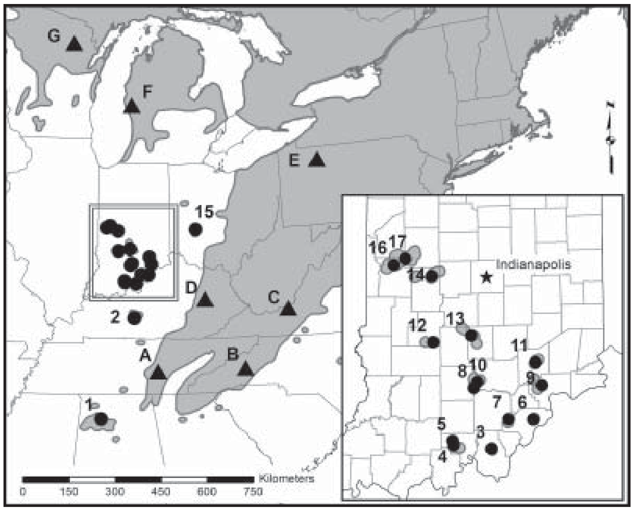

Figure 1: Location of sample populations. Distribution of eastern hemlock (Little 1971) is shaded in grey. Disjunct populations are shown with circles and are numbered 1-18. Reference populations are shown with triangles and are lettered A-G. Names of sample sites are as follows: 1 = Bankhead National Forest, 2 = Mammoth Cave National Park, 3 = Indian Creek, 4 = Hemlock Cliffs, 5 = Yellow Birch Ravine Nature Preserve, 6 = 14 Mile Creek, 7 = Whiskey Run, 8 = Guthrie Creek, 9 = Big Creek, 10 = Hemlock Bluff Nature Preserve, 11 = Muscatatuck River, 12 = Greens Bluff Nature Preserve, 13 = Trevlac Bluff, 14 = Big Walnut Creek, 15 = Clifton Gorge Nature Preserve, 16 = Turkey Run State Park, 17 = Shades State Park, A = Fall Creek Falls State Park, B = Pisgah National Forest, C = Mountain Lake Biological Station, D = Red River Gorge, E = Allegheny National Forest, F = Manistee National Forest, G = Cathedral of the Pines State Natural Area.

2, P=0.035), as estimated by the known areas of these populations. Disjunct populations showed neither a decrease in genetic diversity as distance to source populations increased (Figure 3, P=0.55), or positive correlation between genetic distance (F_{st}) and spatial distance (Figure 4, P=0.87). Finally, while patterns of between-population genetic distance were complex, no strong pattern of differences between disjunct populations were observed between disjunct populations.

In summary, our results support the expectations of the glacial relict hypothesis, where the species is expected to have been once more widespread in this region following the last glacial maximum and has since contracted to the small, isolated populations observed today. There is little evidence to support the formation of these populations through long-distance dispersal events from source populations. Our conclusion agrees with previous understandings of how “relict” communities in the central hardwood forest had formed (Braun 1928) and with results found in other conifer systems worldwide (Richardson et al. 2002, Zhang et al. 2005). Our data also suggest the presence of separate glacial refugia on both sides of the southern Appalachian Mountains, with several unique alleles and clades found only in populations west of the Appalachians, such as the population sampled at Mammoth Cave National Park. This pattern of distinct eastern and western refugia largely corresponds with findings by Potter et al. (2012). If true, this pattern should be of particular interest to conservation efforts to preserve the

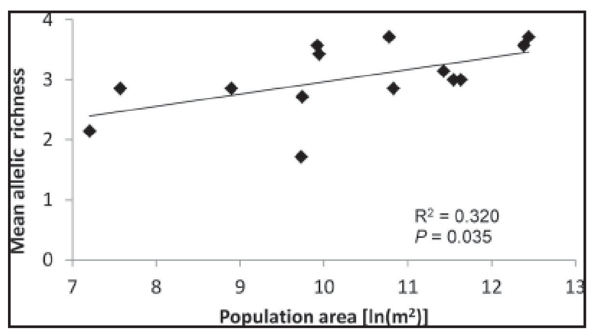

Figure 2: Population size of disjunct populations, as estimated by geographic area of stand, is positively correlated (P=0.035) with mean allelic richness of each population across all seven microsatellite loci. Area of stand was determined using aerial infrared imagery which was only available for the state of Indiana. Therefore, the three disjunct populations not located in Indiana are not included in this analysis.

diversity of genetic resources in eastern hemlock in light of the threat posed by the hemlock woolly adelgid.

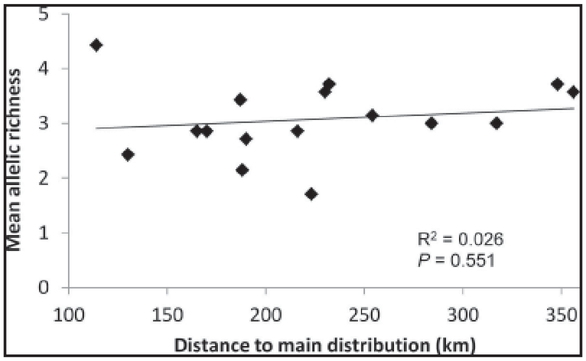

Figure 3: Mean allelic richness is not significantly correlated with distance to the contiguous distribution for the 17 disjunct populations. Distance to contiguous distribution was calculated with the straight line distance to the closest border of Little's 1971 contiguous distribution.

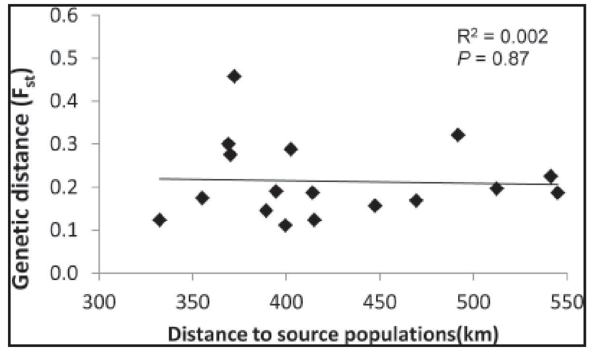

Figure 4: Genetic distance (F_{st}) is not significantly correlated with geographic distance to potential source populations for the 17 disjunct populations. Geographic distance was calculated as the mean distance to the four reference populations to the southwest of the disjunct populations.

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Landscape Genetics of the Marbled Salamander, *Ambystoma opacum*, in a Nationally Protected Park

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Abstract

Landscape features may influence the patterns of migration and dispersal of amphibian species and create genetic structure. A primary goal of landscape genetics is to analyze these influences in order to make more informed management decisions. We sampled larvae from 50 breeding ponds within the boundaries of Mammoth Cave National Park and genotyped 12 individuals per pond at 10 microsatellite loci to estimate gene flow between ponds. We used GIS layers of habitat types to conduct a least-cost path analysis and determine the relative cost of movement through each habitat type. We were interested in answering two questions: does structure exist in this continuous landscape, and does a single pond equal a mating population? Preliminary data indicate that structure does exist at the park. Our results show that a landscape genetics approach is an appropriate mechanism for determining population structure and the size and locations of randomly mating populations.

Influences of a *Cladophora* Bloom on the Diets of *Amblema plicata* and *Elliptio dilatata* in the Upper Green River, Kentucky

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Abstract

Freshwater mussels are the most imperiled group of freshwater invertebrates globally. Recent research suggests a better understanding of mussel feeding ecology may facilitate and improve conservation efforts. The use of stable isotopes is becoming an increasingly common method to study aquatic food webs. Carbon (C) and nitrogen (N) are two of the most frequently employed elements in food web studies. Differences in natural abundance of $^{13}C/^{12}C$ can indicate which food sources are the basal sources of carbon incorporated into a consumer's tissue, while the ratio of $^{15}N/^{14}N$ provides a method of assessing trophic position within a food web. Attached macroalgae, including the genus *Cladophora*, may be the dominant primary producers in running water systems. *Cladophora*, however, has not yet been indicated as a prominent assimilated food source for freshwater mussels. The overall purpose of this study was to assess if the diet of two common Green River mussel species, *Amblema plicata* (Say) and *Elliptio dilatata* (Rafinesque) were influenced by the seasonal change in availability of *Cladophora* during a summer-autumn rapid growth period. Two specific questions were asked: 1) Are the assimilated diets different between control and treatment areas, and 2) are the assimilated diets influenced by differing *Cladophora* levels across the study period? A mesocosm approach was employed in order to manipulate *Cladophora* levels within a treatment area. Seventy-two mussels, 36 each species, were sampled across four months, twice between control (= reach-scale, heavy *Cladophora* cover) and treatment (= local-scale removal of *Cladophora*) areas. The freeware program, IsoSource, a concentration-weighted linear mixing model, was used to determine the potential contribution of potential food sources to the diet of both mussel species. IsoSource revealed that *Cladophora* was the primary assimilated food source for both species across the study period. Although assimilated diets were not different between control and treatment areas, diets were, however, influenced by *Cladophora* availability across time. The results of this study indicate that, during bloom conditions, *Cladophora* is the primary carbon source for both *A. plicata* and *E. dilatata* and may form the base of food webs in the upper Green River.

Contribution of Freshwater Bivalves to Muskrat Diets in the Green River, Mammoth Cave National Park, Kentucky

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Abstract

Muskrats (*Ondatra zibethicus*) are known to prey on freshwater bivalves (mussels and clams) and can negatively impact imperiled mussel species. However, factors that influence muskrat predation on bivalves are poorly understood. We evaluated the feeding ecology of muskrats at Mammoth Cave National Park, Kentucky by using stable isotope analysis of muskrat hair samples and by monitoring bivalve shell deposition at muskrat middens. Bayesian mixing-model analysis of stable isotope $\delta^{15}N$ and $\delta^{13}C$ ratios revealed that the median muskrat biomass derived from bivalves was 51.4% (5th and 95th percentiles were 39.1 to 63.4%, respectively), a much higher dietary proportion than previously reported. Shell depositions by muskrats at middens decreased with the availability of seasonal emergent vegetation, suggesting that the consumption of animal matter is in response to a scarcity of plant foods. Our results add to the growing body of evidence that muskrats have the potential to impact mussel population growth and recovery in some environments.

Potential Effects of Hydrogen Sulfide and Hydrocarbon Seeps on Mammoth Cave Ecosystems

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Abstract

Recently, Mammoth Cave Guide Bruce Hatcher reported what appeared to be contaminated water seeping into Marianne's Pass. I visited the site and concluded that it was not likely due to pollution, and that it was a natural phenomenon. To be sure, I sampled the water for fecal coliform and E. coli analyses since sewer lines are in the area. The results were <1 mpn/100ml in both cases. A sulfur spring is mentioned at this site in Rambles in the Mammoth Cave, which was published in 1845, and this predates any well drilling that could lead to hydrocarbon and sulfide pollution. Another line of evidence that the seeps are natural is that they are all deeply weathered into the bedrock, which takes a long time. The seeps support thousands of springtails, which feed on the microbial mats, and crickets are common as well. A possible effect on biodiversity will be discussed.

A source of hydrogen sulfide in the headwaters of Mammoth Cave

In Mammoth Cave, biological communities are primarily supported by organic matter produced in the near term by photosynthesis. However, virtually anywhere in the region, water with hydrogen sulfide can be reached by drilling 500 feet (150 meters) or less as is common for water wells. Hydrogen sulfide can be used by sulfur oxidizing bacteria as an energy source to convert carbon dioxide into organic carbon molecules in a process known as chemosynthesis. In general, such sulfide-rich water must be pumped up from below, but there are cases in the region where these waters have risen under artesian conditions.

Cutting across much of the Central Kentucky Karst is a structural warp or monocline where the bedrock dips more sharply to the north, and this can be seen in Figure 1 as an east-west band where the structural topographic contour lines are close to each other. Along this monocline there are three known places where sulfurous brine has or currently rises under artesian conditions. Also in Figure 1, the location of Sulphur Well (SW) is shown. Based upon the presence of other brine seeps nearby, in 1845 Ezekiel Neal drilled for saltwater at this location where today Highway 70 crosses the South Fork of the Little Barren River. At a depth of 180 feet (55 meters), the 100 pound (45 kilogram) auger and the 180 feet of drill pipe were suddenly ejected from the well and flew over the top of a large sycamore tree. Water shot from the 6 inch (15 centimeter) diameter well to a height of 20-30 feet (6-9 meters) for an extended period (Sulphur Well Homemakers, 2000). Today the water continues to slowly rise up and out of a concrete structure built around the well casing at a road side park in this small community.

Sulphur River (SR) is shown near the center of Figure 1. This is one of five streams within Parker Cave, and the source of the sulfurous brine was interpreted to be from oil wells in the vicinity (Quinlan and Rowe, 1978). Olson (1992) raised the question of whether the source of Sulphur River was a case of oil well pollution or a natural rise of brine, but no solid conclusions could be reached. I was unaware at the time of the

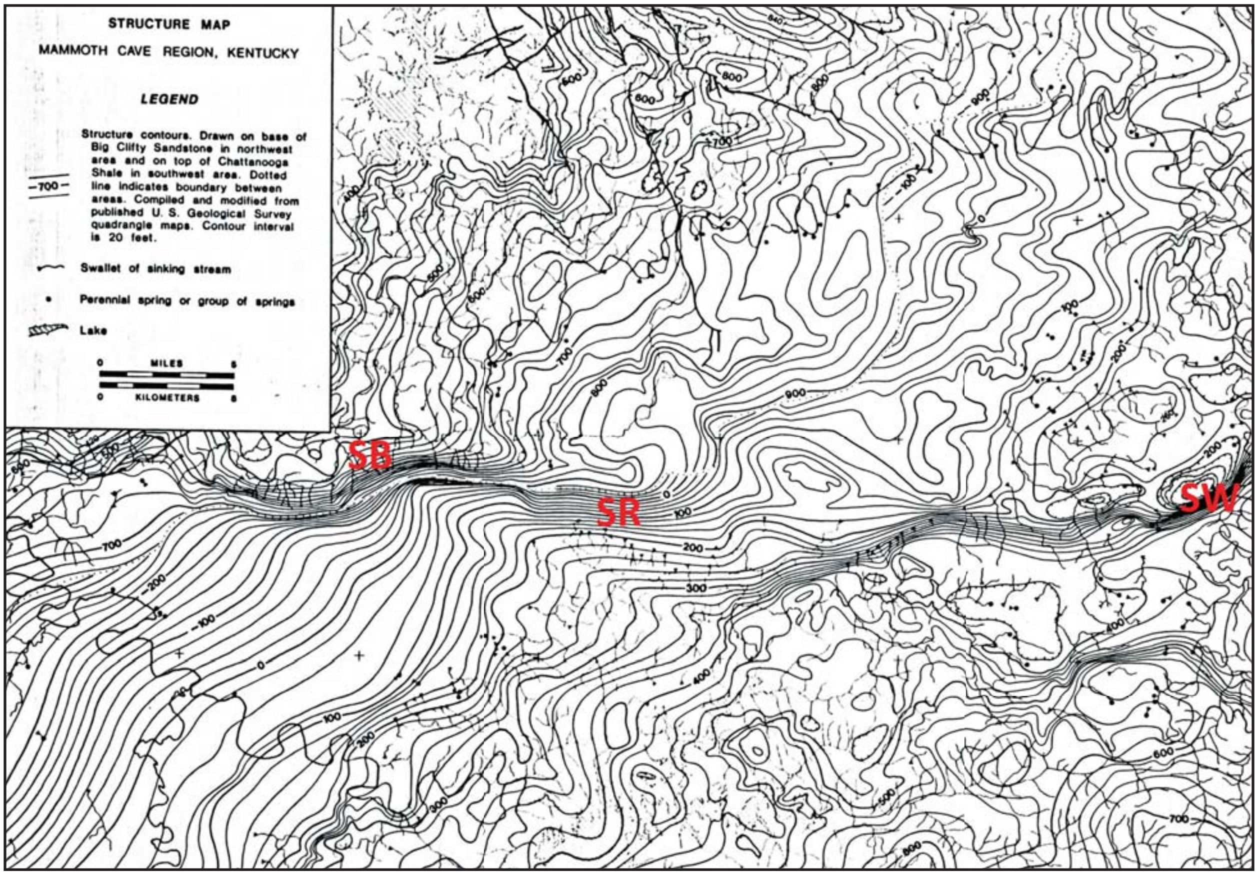

Figure 1: Map showing geologic structure contours in the South Central Kentucky Karst. The east-west band where the structural topographic contour lines are close to each other is a monocline where the bedrock dips more sharply to the north. Known sulfur brine rise sites are indicated by SW (Sulphur Well, SR (Sulphur River), and SB (Sulphur Branch of Alexander Creek). Modified from Quinlan and Rowe, 1978.

other natural brine seeps associated with the structural monocline seen in Figure 1. Unlike other sites where brine rises along the monocline, Sulphur River in Parker Cave has been extensively studied (Angert, et al 1998, Thompson and Olson 1988, Roy, 1988, Olson and Thompson 1988). The sulfurous brine enters at ceiling level in an otherwise normal stream canyon. Hydrogen sulfide in the air reacts with water on the ceiling of an upper level room off the stream canyon to make sulfuric acid drips that were measured at a pH of 0.13. Despite the high levels of atmospheric hydrogen sulfide, diversity of cave life in the Sulphur River passage is high. Two types of annelids, a cave snail, five species of collembolans, a psocopteran, two types of beetles, one type of spider, and several species of mites were collected (Lisowski, et al 1985). As well, the sulfuric acid appears to have significantly enlarged this room from the original small crawl (Figure 2), and this could not happen in the years since the oil boom of the 1920s.

Sulphur Branch of Alexander Creek (SB) is shown in the left-center of Figure 1. In years past, Chameleon Spring was located just west of Chalybeate, Kentucky (Peale, 1886). There was even a hotel in what was called Sulphur Hollow, where people came to “take the waters” (Warnell pers

Figure 2: Photo of the author in the enlarged room where sulfurous brine enters Sulphur River in Parker Cave. Condensate droplets in this room are acidic due to mixing of hydrogen sulfide and water, resulting in sulfuric acid with a pH of 0.13. Photo by Norm Pace

comm, C.S.R. 1829). As people in the region drilled water wells for domestic use, the aquifer was modified to the extent that the sulfurous water no longer flowed from the springs, and the hotel is no more. It is remarkable that sulfurous brine was able to rise up through the Big Clifty Sandstone and into the Haney Limestone.

This discussion may seem somewhat removed from Mammoth Cave, but the point is that water rich in hydrogen sulfide has a means to rise high enough to enter the headwaters of drainage basins feeding into the Mammoth Cave system. We know of three locations along the structural monocline where brine has been documented, but there could be many more like Sulphur River that we do not know about. Energy inputs from photosynthetic sources are seasonal, but energy inputs from chemosynthetic sources are not, and so biomass from this latter source could help provide a floor to the minimum level of food supply coming into the Mammoth Cave System. It should be noted that there are other sulfur springs in the region that are not associated with the monocline discussed here, and each of those has a geological story to be told.

A sulfurous hydrocarbon seep in Mammoth Cave

In 2007, Bruce Hatcher reported unusual organic-rich seeps in Marianne's Pass in Mammoth Cave. He was concerned that there might be a sewer line leaking because there was an ongoing sewer leak in the Mammoth Dome area of the cave. However, he also noted a slight hydrocarbon odor that was not consistent with sewage. Dr. Rick Toomey, Director of the Mammoth Cave International Center for Science and Learning, visited the seeps in Marianne's Pass and photographed the most prominent of them along with thousands of springtails on the moist organic-rich surfaces of the seeps. Crickets and cave beetles are also common near the seeps. We discussed possible sources for these low flow inputs, and concluded that a sewer line leak was unlikely but worth considering because there are sewer lines in the vicinity that run from the Snowball Room restrooms to the elevator where pumps lift the sewage to surface lines (Figure 3)

The surface sewer lines are on the Big Clifty Sandstone, which is part of the caprock over the major carbonate strata that host Mammoth Cave, and which largely deflects runoff to the ridge margins. However, water does enter the cave at Mary's Vineyard, and samples were collected for coliform

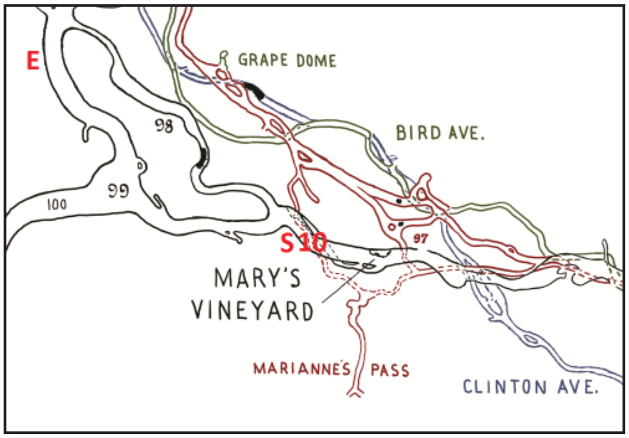

Figure 3: Map showing Marianne's Pass, Mary's Vineyard, Cleveland Avenue, Marion Avenue, and the elevator. "E" on the map shows the location of the elevator, and "S10" shows the location of sulfurous hydrocarbon seeps in Marianne's Pass. Map by Max Kaemper in 1908, digitally restored by Tres Seymour.

bacteria analysis. The results from Western Kentucky University's Waters Laboratory indicated very low coliform bacterial counts (10 colony forming units per 100ml). For comparison, sewer leaks yield results in the thousands of colony forming units per 100 ml. This made a sewer line leak highly improbable as a factor in the unusual organic-rich seeps, but in order to rule it out I collected water at the seeps in Marianne's Pass for both E. coli and fecal coliform bacterial analysis. The results were <1 mpn*/100ml in both cases, which is to say completely negative. *mpn=most probable number.

The Mary's Vineyard waterfall is 112 feet (34m) southeast (122degrees) of Station S10 in Marianne's Pass and only 14 feet (4.3m) higher according to the Cave Research Foundation survey of this area, which is close enough that one might think they could be linked. However, the seeps in Marianne's Pass appear to be totally unrelated for at least two reasons. First, the flow rate is far less in Marianne's Pass than at Mary's Vineyard, and second, the Mary's Vineyard waterfall has its own unusual water chemistry resulting in dolomite precipitation (Palmer, pers comm), which is not happening in Marianne's Pass. Far from it, the water seeping in here has heavy microbial mats with black and white precipitates like those seen where hydrogen sulfide is being oxidized (Figure 4). No hydrogen sulfide odor is apparent in Marianne's Pass, but Art and Peg Palmer brought in a portable test kit in April of 2010, and 0.15 mg/l of hydrogen sulfide was detected. Normally, seeps of water in the cave have no detectable hydrogen sulfide because of oxygen in the air and dissolved in the water. All this suggests the chemistries of these two waters are completely different because they have different sources: the Mary's Vineyard waterfall is coming in from the surface, and the Marianne's Pass seeps are coming up from below. I considered that the hydrocarbon seeps might be coming up an abandoned oil well within the park, but there are two contraindications: first this feature was reported by Bullitt (1845) as "a sulphur spring", and second, the seeps are weathered into the limestone walls – a process that would take a great deal of time. Though Marianne's Pass is located within a structural syncline or swale (Palmer 1981), there is no dramatic structural feature, like

Figure 4: Dr. Horton Hobbs III at the seeps in Marianne's Pass. Photo by author.

the monocline to the south, to provide a plausible reason why fluids would rise from deep below.

In 2009, a set of fractures were observed in the bedrock a little northwest of Mary's Vineyard where Marianne's Pass crosses below. In Figure 5, Guide John Yakel is pointing to an intersection of fractures at this same location, which has abundant popcorn and some water dripping in from above at this otherwise dry location. If this fracture intersection allows water to seep in from above, then it could also allow water to rise from below. Water dripping in from above is easy to understand, but water defying gravity is another matter. However, hydrocarbon deposits in the area can be under considerable pressure and could provide the motive force to overcome gravity. For example, an oil strike at Arthur, Kentucky produced a gusher in recent times (Kentucky New Era, 1995). The report of an oil gusher on the Crystal Cave property by Dr. H. B. Thomas may have been real or may have been theater to drive up the price of the Crystal Cave property prior to acquisition by the National Park Service (Edmonson News 1931).

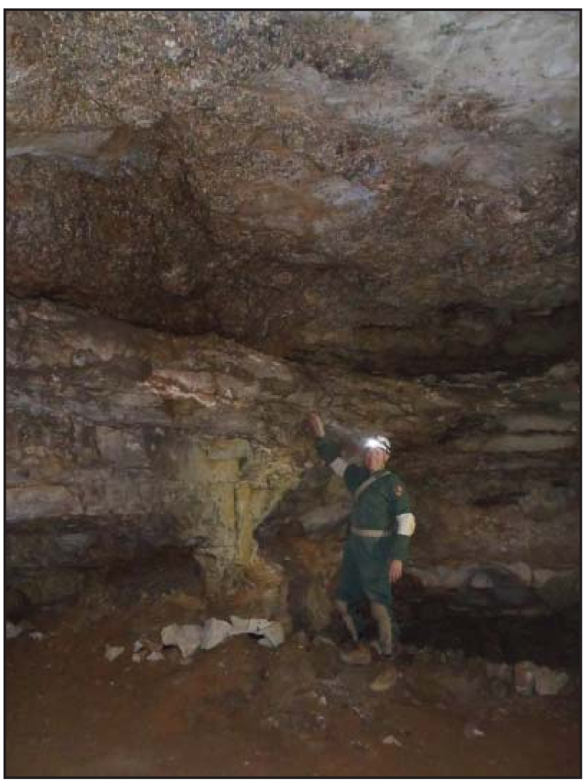

Figure 5: Dr. John Yakel at a fracture intersection in Cleaveland Avenue near Mary's Vineyard. This location is in the vicinity of Marianne's Pass, which crosses only 14 feet below. Photo by author.

Conclusion

Mammoth Cave is known not only for its great extent, but also for the great diversity of cave life. The basis of this biodiversity hot-spot was interpreted by Barr (1967) to be a result of the great length of the cave, variety of habitat types, and geographical conditions conducive to dispersal of troglobites. Poulson (1997) summarized the relevant factors as "history and current geology, hydrology, and kinds of input of allochthonous organic matter that is the food base for virtually all the ecosystems". Speaking of caves more generally, Culver and Sket (2000) attributed high biodiversity to great areal extent of karst, high productivity such as chemoautotrophy, inclusion of phreatic habitat within caves, and length of caves. The high biodiversity of Mammoth Cave was not discussed in the context of chemoautotrophy, but perhaps it should be considered in this light. One significant input exists at Sulphur River, but there could be many more that are cryptic. Though the water from Sulphur River does not flow to Hawkins River, I have observed many times that water in this stream at the junction with Logsdon River has a milky turbidity consistent with colloidal sulfur, which is a consequence of hydrogen sulfide oxidation. This is one location that could be investigated to gauge the impact of hydrogen sulfide upon the energetics of Mammoth Cave's aquatic ecosystem.

Hydrocarbon inputs should be considered as well, because even though this energy source would be consumed by heterotrophic bacteria, this type of energy source is distinct from organic matter produced via recent photosynthesis. Study of the seeps in Marianne's Pass has only begun and there are many more questions than answers at this time. No similar seeps have been found in the cave to date. However, if one thinks of Mammoth Cave in terms of scale, then how many passages too small for us to access exist? Cave animals can use tiny tubes and canyons far too small for us to visit, and it is possible that there are other such seeps in those spaces.

Acknowledgements
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Long-Term Monitoring of Cave Aquatic Biota Using Occupancy Modeling

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Abstract

Monitoring populations of organisms over time is difficult even under the best circumstances; this is especially true of cave organisms. Cave organisms may not be detected during a monitoring survey even though they may be present. Indeed, detectability, i.e., the probability of detecting target taxa during a survey given they're present at the site, undoubtedly varies among cave habitats (e.g., terrestrial versus aquatic) and cave organisms (e.g., cave beetles versus cave fish). However, to make reliable inferences regarding the relationship between the probability a sampling site is occupied by a cave organism (i.e., occupancy) and abiotic/biotic factors that affect it requires analyses of imperfect detection. Detectability can be used to model occupancy which can, in turn, be used as a surrogate for abundance. The proportion of sites occupied by the target taxon can be used as a variable to characterize the status of purportedly sensitive cave aquatic ecosystems.

Antibiotic Resistance and Substrate Utilization by Bacteria Affiliated with Cave Streams at Different Levels of Mammoth Cave

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Introduction

Located in south-central Kentucky, Mammoth Cave is one of the most unique National Parks in the United States. The surface landscape includes complex relationships between the flora and fauna along with human influences. However, the primary ecological focus is concealed below ground. Over four-hundred miles of cave passages, created by flowing groundwater over millions of years, host a variety of macro and micro organisms. The Green River has cut into the limestone formation over geologic time, creating a complex network of passages that are stacked, one below the other, with the newer levels of cave lying near the bottom. Palmer (2007, 1987) describes 4 main levels of cave passages in the Mammoth Cave system. A detailed discussion of the geology and conditions that formed the cave levels can be found in several reports (Palmer, 1987; Palmer 1989; White and White, 1989; Granger, et al, 2001). Precipitation continues to provide water that traverses from the surface, through the unsaturated vadose levels of the cave, and down to the water table in the lower level. Water enters the cave system through direct recharge at sinkholes and through diffuse percolation. The rapid infiltration of stormwater often exceeds the carrying capacity of the upper cave passages and excess water is pushed into void pore-spaces near the top of bedrock. This stored water is slowly released and provides base-flow to cave streams that replenish the pools and streams in the lowest level of the cave (Ryan and Meimen, 1996). These perennial cave streams carry many of the organic compounds that provide energy to the cave ecosystem (Barr, 1976).

During May 2011 to August 2012, the Park endeavored to prevent the spread of *Geomyces destructans* spores by using mats that were saturated with a quaternary ammonia compound (QAC) solution to disinfect the footwear of everyone who entered the cave. QAC residue on the ground near the disinfection stations was visibly evident during prime tourist season. This heavy use of QACs raised concern about the potential for the disinfectant to be carried into the cave via storm runoff. Also, there was concern about QACs in accidental leaks associated with the recreational vehicle wastewater disposal (Diehl and others, 2012). These potential QAC sources were all within the small River Styx watershed boundary. One potential consequence of QAC in the River Styx watershed was that it could lead to selection of QAC-resistance in the microbial community. Previous research found that bacteria resistant to QACs were likely to be resistant to other antibiotics (Chapman, 2003). Accordingly, it was possible that repeated exposure to QACs could also lead to resistance of medical antibiotics. There was additional concern that QACs may inadvertently act as microbial signals (Keller and Surette, 2006) or disrupt natural biogeochemical cycles (Underwood and others, 2011) at sublethal concentrations.

Microorganisms play an essential role in the health of Mammoth Cave's ecosystem, yet the ecology of microbial communities in the cave streams has been largely neglected (Barton and Northup, 2007). Most of the scientific literature concerning cave microbiology addresses microbes that live on the cave walls and sediments (Rusterholtz and Mallory, 1995; Northup and Lavoie, 2001; Barton, and others, 2007) or speleothems (Palmer 2007). This project begins to address the gap in microbial ecology of cave streams.

This collaborative project between the U.S. Geological Survey, Mammoth Cave National Park, Tennessee State University, and Mammoth Cave Learning Center focused on the microbial communities associated with the perennial cave streams in four levels of Mammoth Cave. The objective of this project was to determine the substrate utilization and dose-response to five antibiotic compounds in the microbial communities of cave streams. Sites selected for the study correspond to perennial water from three different levels of the cave within the River Styx Spring basin. The River Styx basin is a small, 1.2 square mile watershed, located beneath the campgrounds to the Visitors Center. Water samples used for microbial analysis were collected during the summer of 2012. Base-flow samples were used for most of the analysis since that would reflect the ambient condition in the cave streams. It should be noted that Central Kentucky experienced a severe drought during the summer of 2012, which also affected our ability to collect storm samples.

Methods and Materials

Site description

The sampling sites were selected to represent different levels in the cave system (Figure 1). The Post Office parking lot was selected as a surface site for storm sampling. Previous storm sampling had found QACs associated with the RV wastewater disposal system (Diehl and others, 2012). A quantitative dye study in December of 2011 found that it took approximately 75 minutes for the tracer from the parking lot storm filter discharge to cascade down Annette's Dome located in the upper part of cave Level B, and is the beginning of Shaler's Brook (Embry and others, 2012). It took another 20 minutes for the dye to reach Lee's Cistern in lower Level B. The tracer study failed to show that water flowed from Lee's Cistern to Charlotte's Dome (Level C) and Charon's Cascade (Level D). The Devil's Cooling Tub, located near the south-east end of Gratz Avenue, cave level B, was also found to be hydraulically connected to the Post Office runoff. However, it took approximately a month for the tracer released at the Post Office to reach the Devil's Cooling Tub. A stagnant pool mid-way along Gratz Avenue (level B) was selected because it represented a different hydrologic setting from Annette's Dome, Lee's Cistern and Devil's Cooling Tub.

Water samples for microbial analysis were collected approximately every 2 to 3 weeks in the summer of 2012. Grab samples were collected during base flow using clean sterile 250 mL bottles. A first flush storm sampler (Diehl, 2008) was also used at the Post Office filter discharge pipe and in Annette's Dome. The water samples were brought back to the lab in Nashville and stored at 5oC until analysis was done.

Analysis included bacteria plate counts using 2% agar containing 10% strength Tryptic Soy nutrients (10% TSA). Previous work by Byl and others (2002) found karst groundwater bacteria grew better on low strength media than full strength TSA. Known concentrations of the antibiotics QAC, tetracycline, gentamicin, kanomycin, and erythromycin, were mixed into the

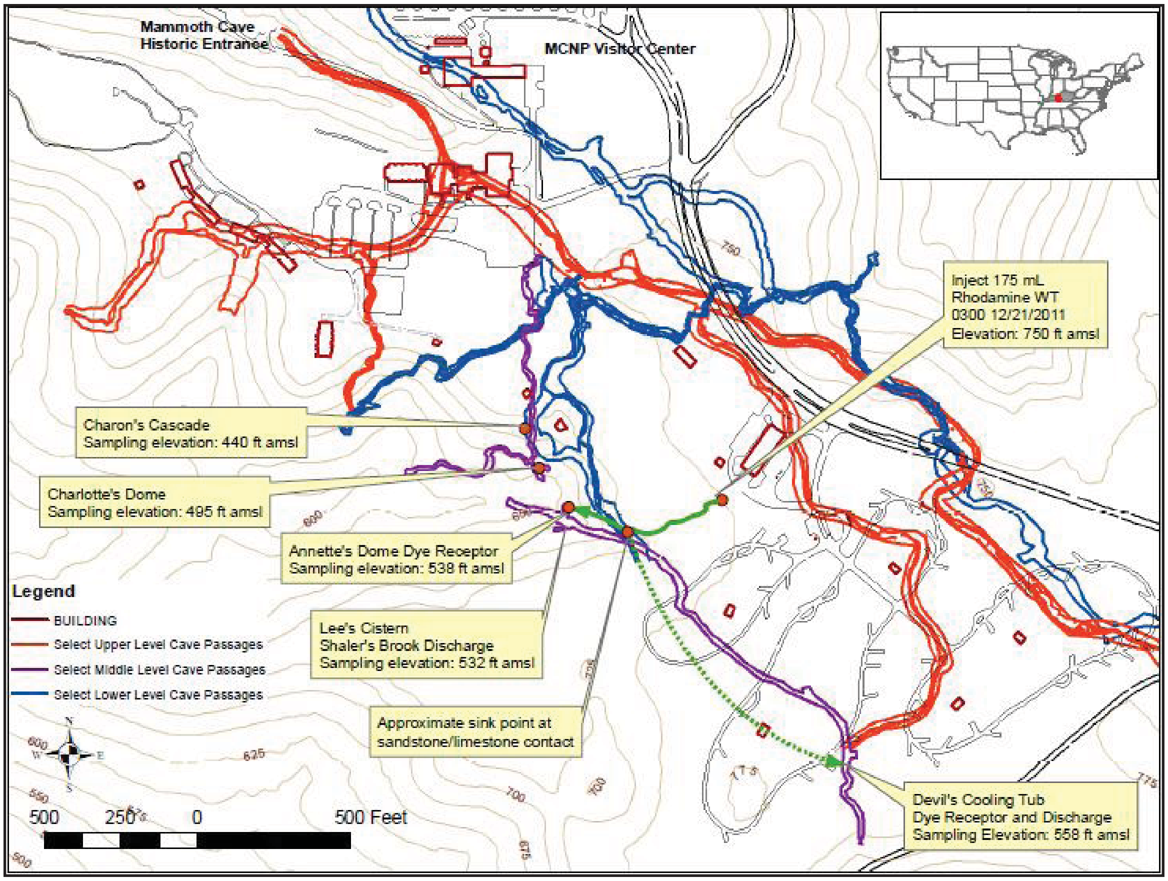

Figure 1: Map depicting sampling sites. Surface water samples were collected at the dye injection point by the Post Office storm filter. Three levels of the cave are represented in this study, levels B (red), C (purple) and D (blue). Flowpath of the Rhodamine-WT tracer is represented in green.

10% TSA just prior to pouring the plates. The cave water samples were hand shaken for a minute to re-suspend the bacteria, and a 10 uL aliquot of raw water was placed on the agar. The cave water containing bacteria was evenly spread over the plate using a sterile bent glass rod. Innoculated plates were inverted and placed in an incubator at 25°C. The bacteria colonies were counted at 1, 2, and 3 days. The results are reported as colony forming units per 10 uL.

The microbial metabolic capabilities were characterized using Biolog's Ecolog™ plates to determine community-level physiological profiles. The plate has 31 different substrates, and three replicates of each substrate (Stefanomicz, 2006). The strength of the bacteria inoculums were normalized by diluting the cave waters with sterile distilled water to a standard turbidity of 1 nephelometric turbidity unit. Standardizing the inoculum, as described in Haack and others (1995), assured that observed differences in community-level physiological profiles were not simply due to differences in bacteria concentration. Readings of the plates were taken at 12, 24, 48, 72, 96, and 120 hours. Analysis included richness, Average Well Color Development (AWCD) (Stefanowicz, 2006), and, Gini coefficient (Harch and others, 1997). Stata™ statistical package was used to calculate the

Gini coefficient. The richness is a measure of how many substrates the bacteria community used. AWCD is an indicator of community metabolic rate. The Gini coefficient is a measure of how evenly the bacteria used the 31 substrates.

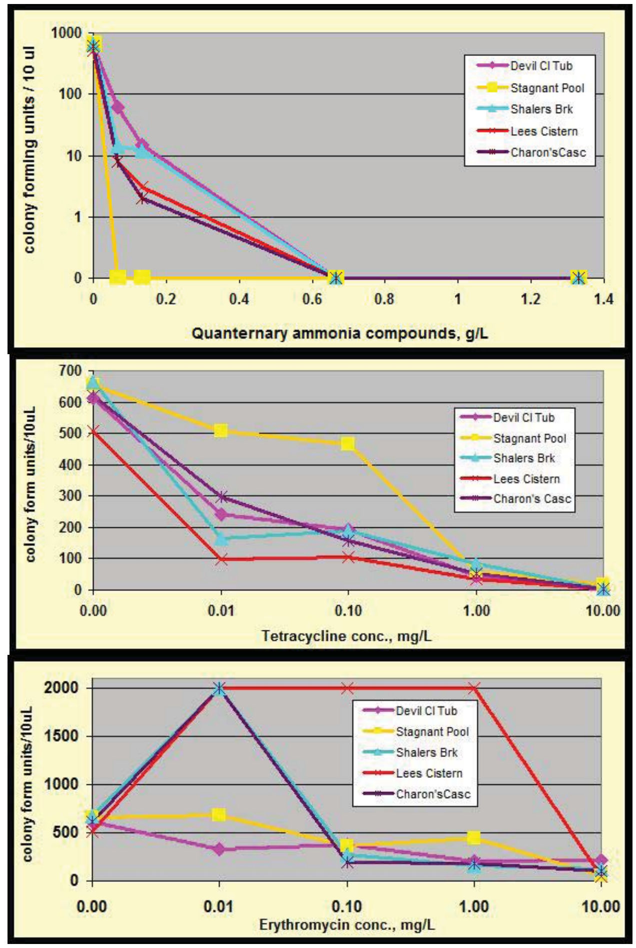

Figure 2a-c (top – bottom): Dose-response of bacteria collected in different waters of Mammoth Cave National Park to QAC, tetracycline, and erythromycin.

Results

The results of this project are split into two subsections, antibiotic resistance and substrate utilization by the microbial communities. Antibiotic resistance evaluations were achieved by running dose-response tests on 10% TSA plates dosed with increasing concentrations of antibiotics. The substrate utilization tests used Ecolog™ plates to quantify community-level physiological profiling by providing 31 potential food substrates for the bacteria communities to consume over a 5 day period.

Antibiotic resistance

The antibiotics used in the antibiotic-resistance tests included QAC, tetracycline, gentamicin, kanamycin, and erythromycin. Bacteria collected from various cave streams and a pool were sensitive to increasing concentrations of QAC (Figure 2a). The QAC effectively inhibited growth of bacteria at concentrations of 0.66 grams QAC per liter and above. Figure 2b shows the microbial growth response to increasing concentrations of the medicinal antibiotic, tetracycline. The bacteria show atypical dose-response curve, with decreasing numbers of colony forming units as the concentration of tetracycline increases. The dose-response pattern was very similar for the antibiotics gentamicin and kanamycin (not shown). Adding the antibiotic erythromycin to the agar media produced a very different dose-response (Figure 2c). Erythromycin actually stimulated the growth of bacteria colonies at doses of 0.01 to 1.0 mg/L. However, 10 mg/L erythromycin inhibited colony formation.

The erythromycin results were different from the other antibiotics tested, so a second test was conducted using a new sample collected from Lee's Cistern. This time, there were three replicate plates for each erythromycin concentration to allow a Student T-test, $p = 0.05$. The results are shown in Figure 3. A similar pattern was observed, where 0.01 to 1 mg/L erythromycin stimulated the number of bacteria colonies. There was a significant decrease in bacteria colonies grown on media with 10 mg/L at 24 and 48 hours. There were significantly more bacteria colonies on media containing 0.1 and 1.0 mg/L erythromycin after 48

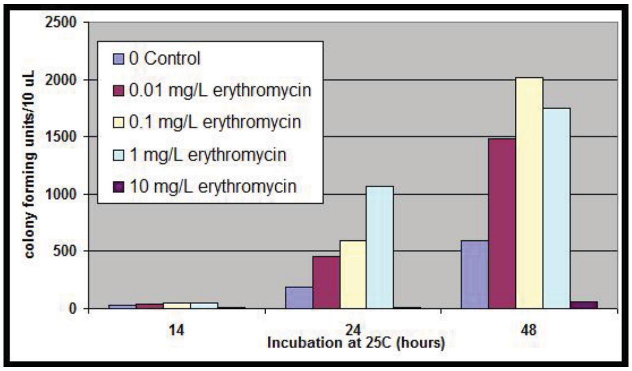

Figure 3: Bacteria from Lee's Cistern were stimulated by low doses of erythromycin. Bars represent average of 3 replicate plates containing increasing concentrations of erythromycin. [* indicates significant difference from controls at p=0.05]

hours. Thus it appears erythromycin has a stimulatory effect on the cave bacteria at low concentrations and a toxic threshold between 1 and 10 mg/L.

Substrate utilization tests

The Biolog™ results from the Post Office storm drain (surface), Shaler's Brook (upper level B), Lee's Cistern (lower level B), Charlotte's Dome (level C), and Charon's Cascade (level D) are provided in this section. The data analyses include substrate diversity (substrate richness), an indicator of metabolic rate (Average Well Color Development), and substrate evenness (Gini coefficient).

The samples collected on the surface and in the upper levels of the cave had the greatest initial substrate richness values (Figure 4). Charlotte's Dome (level C) was an exception and had relatively high richness. However, the rate at which the microbial community from Charlotte's Dome used the substrates was slow (Figure 5). After 72 hours, the richness values for all the sites tested were similar (Figure 4). This indicates there was an initial preference for certain substrates, but given time, the bacteria communities can utilize almost all 31 substrates to some extent.

Substrate richness and AWCD are useful measures of microbial ecology, but do not provide information about how evenly the microbial community utilized the 31 substrates. The Gini coefficient is a statistical measure of evenness in a population, ranging from 0 to 1, with 1 being the most uneven and 0 being perfectly equal use of all the substrates. The Gini coefficient values decreased in the first 72 hours, indicating that substrate utilization became more even (Figure 6). However, the Gini coefficient from samples collected from deeper in the cave (Charlotte's Dome, level C, and Charon's Cascade, level D) leveled off after 72 hours, indicating that a steady state had been reached. After 120 hours incubation, it was evident that the microbial communities from or near the surface used the substrates more evenly than the communities deeper in the cave.

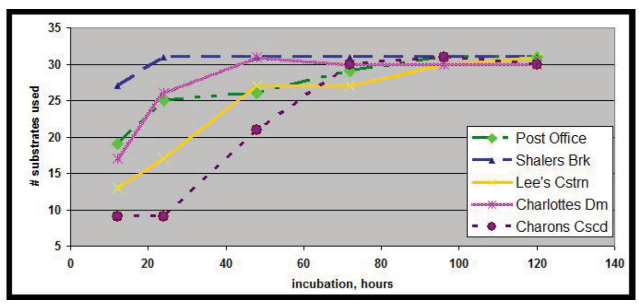

Figure 4: Substrate richness for the different bacteria communities through time.

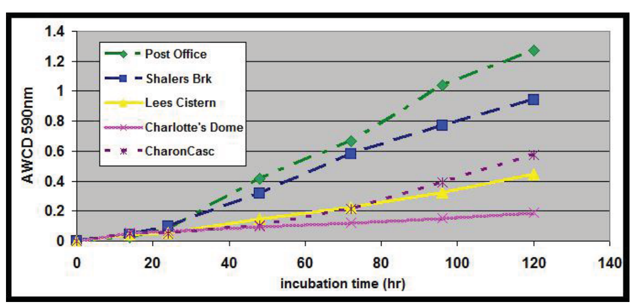

Figure 5: The Average Well Color Development (AWCD) is an indicator of metabolic rates; the steeper the slope, the faster the metabolic rate of the microbial community.

Summary and Conclusion

This project looked at the response of cave microbial communities to five antibiotics and their substrate utilization patterns. The cave bacteria appear to be sensitive to QACs, with a slight resistance at the upper cave levels. The bacteria communities in the cave have varying levels of natural resistance to the other four antibiotics tested. Low doses of erythromycin stimulated bacteria growth. Further studies are needed to determine if erythromycin occurs in this environment to determine if it is a microbial messenger in this environment. Using the Ecolog substrate utilization plates, we found that substrate richness, metabolic rates and evenness of substrate-use tend to decrease in communities deeper in the cave, with some exceptions. There is a shift in microbial physiological capabilities associated with the different levels in the cave system. It should be noted that since the sampling took place during a particularly hard drought, the distinct microbial community patterns described here may vary under different weather or seasonal conditions.

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The Cave Beetle *Neaphaenops tellkampfi* Erichson: Relationships Within and Among Related Genera Using Molecular Data

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Abstract

Studies of North American cave beetle systematics have been based primarily on morphology. This project analyzes the relationships and validity of the four subspecies of the monotypic *Neaphaenops* based on monophyly, as well as relationships with the remaining four eastern N.A. cave beetle genera (*Pseudanophthalmus*, *Nelsonites*, *Darlingtonea*, and *Ameroduvalius*) using molecular methods. This study utilized 39 beetle samples collected from 27 Kentucky caves and one outgroup accessed from GenBank. Evidence for phylogenetic hypotheses is based on sequences of one nuclear protein-coding gene (arginine kinase) and one mitochondrial gene (CO1). Analyses support *Neaphaenops* as sister to all other taxa. One subspecies of *Neaphaenops* is valid, a second possibly so, and the other two are not. All tested genera are monophyletic except for *Pseudanophthalmus*; *Nelsonites* appears to be a derived clade of *Pseudanophthalmus*.

A Functional Visual System in the Cave Beetle *Ptomaphagus hirtus*

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Abstract

Cave species exhibit a suite of dramatic differences in comparison to their surface living relatives, commonly referred to as troglomorphy (Christiansen 2005). One hallmark feature of troglomorphy is the severe reduction or complete loss of eyes and functional vision. The two most abundant cave beetle species in Mammoth cave, the 2-3 mm small carrion beetle *Ptomaphagus hirtus* (Packard 1888; Peck 1973; Peck 1975; Tellkampf 1844) and the 6-8 mm long predatory ground beetle *Neaphaenops tellkampfii* are good examples of this (Barr 1979). *P. hirtus* tends to hide in crevices and usually goes unnoted to the regular visitor of Mammoth cave. *N. tellkampfii* by contrast is very active and therefore noticed by most attentive visitors of Mammoth cave as the fast moving insect crossing their path. Neither of these two beetles possesses compound eyes typical for diurnal insects (Barr 1962). In *N. tellkampfii*, external eyes as well as the related regions in the brain are completely absent (Ghaffar et al. 1984). Compound eyes are also missing in *P. hirtus*. However, small lens structures can be noted in the lateral head (Figure 1). *P. hirtus* is also flightless because of the complete reduction of the hind wings (Peck 1973). In his comprehensive study of North American cave animals, Alpheus Spring Packard (1888) studied the anatomy of the lens-like structures in *P. hirtus*. He concluded that P. hirtus was blind based on his failure to find an optic nerve connecting from cells underneath the lens structure to the brain.

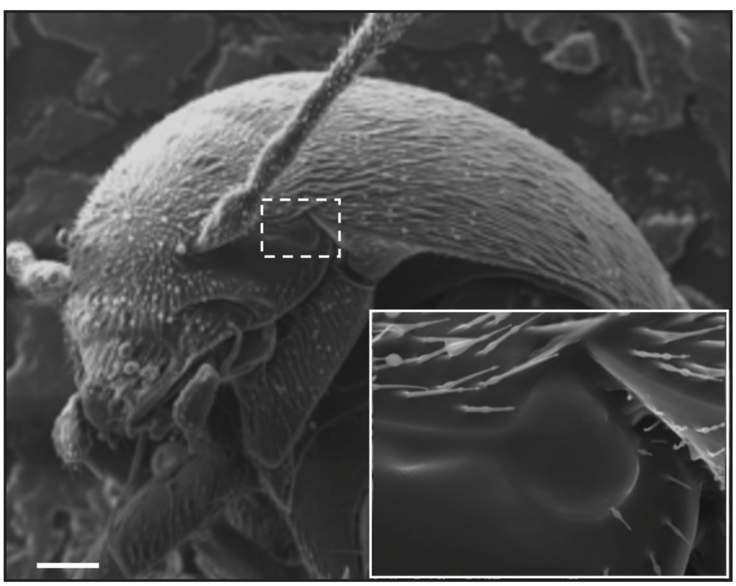

Figure 1: Head and lens morphology in *P. hirtus*. Scanning electron microscopy image view of the *P. hirtus* adult head. Inset: High power view of the lateral lens, outlined by hatched box in the overview image. Scale bar: 100 μm.

A series of experiments in the 70ies established that *P. hirtus* can be easily cultured in the laboratory (Peck 1975). We therefore chose *P. hirtus* for studying the genetic mechanisms of cave adaptation, complementing similar studies in the Mexican cavefish *Astyanax mexicanus* (Jeffery 2005). As a first step into this endeavor, we readdressed the question of vision in *P. hirtus*. Key rationale for suspecting the conservation of a small but functional visual system in *P. hirtus* came from genetic studies in other insects. These have shown that the formation of lens forming cells is absolutely dependent on the preceding differentiation of light-

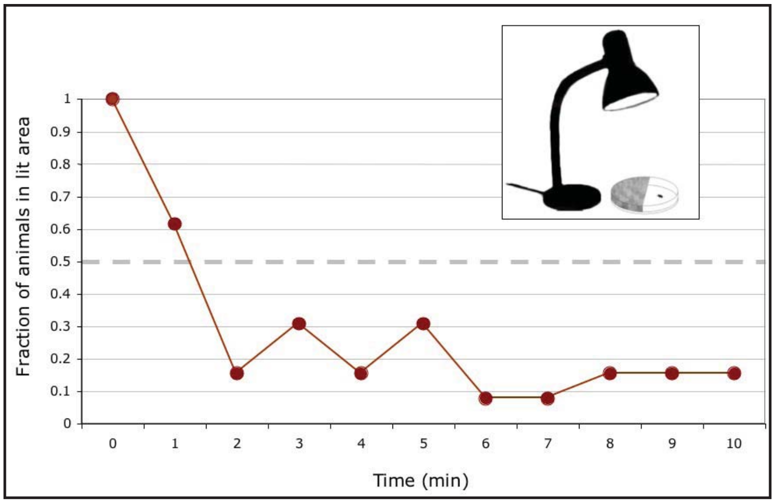

Figure 2: Quantitative analysis of *P. hirtus*' response to exposure to white light. Inset shows test setup. X-axis indicates time points of single observations. Y-axis represents the fraction of test animals present in the lit area of the test arena. Each data point represents the proportion from 13 tested animals. Dashed line indicates neutral expectation. Modified from Friedrich et al. 2011.

sensitive cells (photoreceptors) (Buschbeck and Friedrich 2008). The presence of presumptive lenses in *P. hirtus* therefore suggested the presence of photoreceptive cells in contrast to Packard's earlier conclusions.

We first took a genetic approach test for light-sensitive cells in the adult *P. hirtus* head, employing a new high throughput sequencing method (Nagalakshmi et al. 2008) to probe for the activity of light perception related genes in this species. In the course of this analysis, we characterized the transcript sequences of over 5000 different genes in *P. hirtus*. In the next step, we used bioinformatics methods to search these transcripts for sequences corresponding to genes that are specifically known for their visual function in the widely used model insect *Drosophila melanogaster* (Wang and Montell 2007). This approach revealed the expression of all genes in *P. hirtus* that are currently known to be essential for light perception in insects (Friedrich M. et al. 2011).

As these results strongly indicated the preservation of vision in *P. hirtus*, we subjected laboratory animals to a classic light-dark choice test (Figure 2). These tests revealed a pronounced avoidance of light (negative phototaxis) by the adult animals (Friedrich M. et al. 2011). After only two minutes observation time, on average at least 70% of the tested animals had withdrawn into the shaded area in these experiments. Thus taken together, both genetic and behavioral data produced unambiguous evidence of a functional visual system in *P. hirtus*. In ongoing studies, we are exploring the anatomy and adaptive function of vision in this inconspicuous cave dweller, now to be considered in microphthalmic (small-eyed).

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Seasonal Occurrence and Habitat Affilitations of Trichoptera at Mammoth Cave National Park

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Abstract
The order Trichoptera is an ecologically-important, diverse group of insects. We investigated the relative abundance and occurrence of these insects at Mammoth Cave National Park (MCNP). We focused our efforts on adults captured at blacklight traps placed across four forest habitats in MCNP on 14 nights during 2010-2011. Large-bodied Trichoptera (≥ 10 mm in length) were identified and enumerated, yielding 2,153 specimens of ≥ 45 species and 11 families. Unique captures were recorded at mixed deciduous-dominated, mixed conifer-dominated, and upland deciduous sites (13, 4, and 3 species, respectively). While composition of the assemblage varied across collection sites, as well as seasonally, members of the Hydropsychidae (*Hydropsyche* spp.) and Leptoceridae (*Ceraclea* spp.) were the most abundant groups. These two families constituted 93% of total abundance and 65% of species richness across all samples. In this study we detail abundance and richness patterns of Trichoptera across a forest landscape and examine habitats for which data are lacking.

Introduction

The order Trichoptera (caddisflies) is an ecologically-important, diverse group of insects that are widely distributed across North America (Morse 1993). The aquatic larvae of this order occupy a variety of lentic and lotic habitats and ecological niches and are frequently used by regulatory agencies as water quality indicators. The ecological and practical importance of the terrestrial, short-lived adults (<1 month lifespan) is less well known, but adult Trichoptera do serve as prey for vertebrates such as bats and birds. (Floyd et al. 2012). These factors underscore the importance of diversity assessments for this group in eastern North America, where fragmentation and human impacts on forest habitats are central concerns to land managers and conservationists (Yahner 2000). Consequently, diversity assessments for this and other conspicuous insect taxa are a valuable tool for stewards in establishing diversity benchmarks for management plans (Summerville et al. 1999, Floyd et al. 2012). Bearing this in mind, we sought to identify seasonal patterns of adult Trichoptera, and to document specific habitat affiliations for the species assemblage at Mammoth Cave National Park (MCNP).

Methods

Mammoth Cave National Park encompasses 23,000 ha in Barren, Hart, and Edmonson counties on the edge of the Crawford-Mammoth Cave Uplands of the Interior Plateau of Kentucky (Woods et al. 2002). Our survey efforts took place across an array of upland habitats and, to a lesser extent, along the floodplain of the Green River. Survey sites had been selected previously as part of a larger study investigating the impacts of prescribed fire and forest structure on bat and insect populations at MCNP. Specimens were collected across multiple sites in a given night (≥ 50 m apart) using 10 W blacklight traps (Universal Light Trap, Bioquip Products, Gardena, CA). As per recommendations by Yela and Holyoak (1997) for sampling Lepidoptera, survey nights were fair with temperatures ≥ 16° C at sunset, no precipitation, and low wind. Blacklight traps were suspended 2.5 m above ground prior to dusk and operated throughout the entire night. A dichlorvos-based 'pest strip' (ca. 2×6-cm) was placed within each blacklight trap to subdue specimens. Following a survey night, Trichoptera ≥ 10 mm in length were isolated from the other insects captured and stored in 70% ethanol for later identification in the laboratory. Specimens were enumerated and identified to species level when possible (some female specimens and others of poor quality were left at genus or family). The abdomen of some specimens was removed and cleared in 10% KOH prior to examination to facilitate identification (Floyd et al. 2012). Specimens were identified using morphological characteristics and by making comparisons to existing data from the region (Floyd et al. 2012). Specimens were deposited with MCNP. Records were compiled, with forest habitats noted where specimens were collected. Delineation of habitats followed the Kentucky State Nature Preserves Commission's classification system, as defined in MCNP's Fire Management Plan (NPS 2012). Surveyed habitats included: mixed coniferous-dominant / deciduous forest, mixed deciduous-dominant / coniferous forest, mesic floodplain deciduous forest, and mesic deciduous upland forest.

Results

We examined and identified a total of 2,153 Trichoptera, representing ≥ 45 species and 11 families (Table 1). These totals originated from 14 of 22 survey nights from August 2010 – September 2011 (n = 57 of 169 trap-nights). The most specimens were captured at mixed deciduous-dominant / coniferous sites (n = 1,145, from 16 trap-nights), followed by mixed coniferous-dominant / deciduous sites (n = 632, from 21 trap-nights). Fewer specimens were captured at mesic deciduous upland sites (n = 262, from 18 trap-nights) and mesic floodplain deciduous sites (n = 114, from 2 trap-nights). Hydropsychidae was the most cosmopolitan family, with *Cheumatopsyche pasella* Ross, *Hydropsyche alvata* Denning, and *Hydropsyche simulans* Ross recorded across all habitats. Leptocerid species, *Oecetis inconspicua* (Walker) and *Oecetis persimilis* (Banks), were also recorded across all habitats. Other taxa were more variable, and many records were unique to single habitats. Mixed deciduous-dominant / coniferous sites had the highest number of unique records (n = 13), primarily for leptocerids and hydropsychids (6 and 3 species, respectively). Mixed coniferous-dominant / deciduous sites also had unique records. These included singletons from four families: Leptoceridae (*Triaenodes tardus* Milne), Hydroptilidae, Philopotamidae (*Chimarra aterrima* Hagen), and Rhyacophilidae (*Rhyacophila parantra* Ross). Upland deciduous sites likewise had unique records; these included a lepidostomatid [*Lepidostoma griseum* (Banks)] and two limnephilids [*Pseudostenophylax uniformis* (Betten), and *Pycnopsyche guttifer* (Walker)]. No unique records were found in our sampling of mesic floodplain sites. This was likely attributable to the small number of trap-nights (n = 2). In terms of assemblage richness, leptocerids and hydropsychids dominated records from our surveys (Figure 1). While these two families formed > 65% of the species identified across all months, richness patterns for other families were variable across surveys. We found three families to be most abundant (Figure 2). Hydropsychidae and Leptoceridae dominated our records; these families formed 93% of the total specimens. Phryganeids were less abundant (4% of total specimens), but became prominent in the latter portion of the growing season. Two genera were most abundant in our surveys (Figure 3). A low incidence of

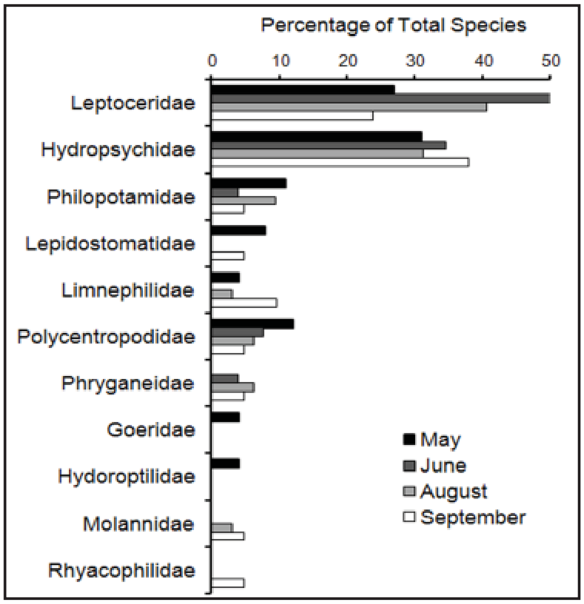

Figure 1: Percent composition of trichopteran families captured in blacklight traps from Mammoth Cave National Park, 2010-2011.

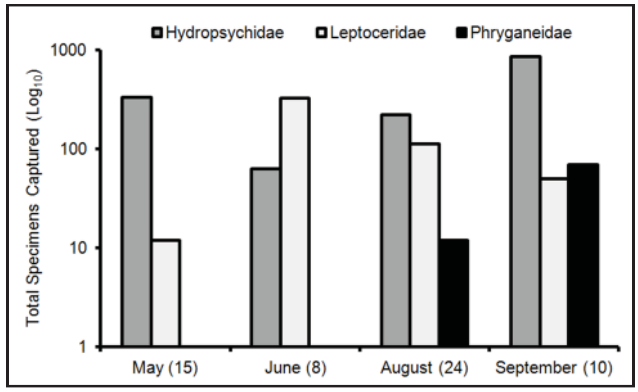

Figure 2: Abundance trends across months for major families of Trichoptera captured in blacklight traps at Mammoth Cave National Park, 2010-2011. Numbers of trap-nights for months are in parentheses.

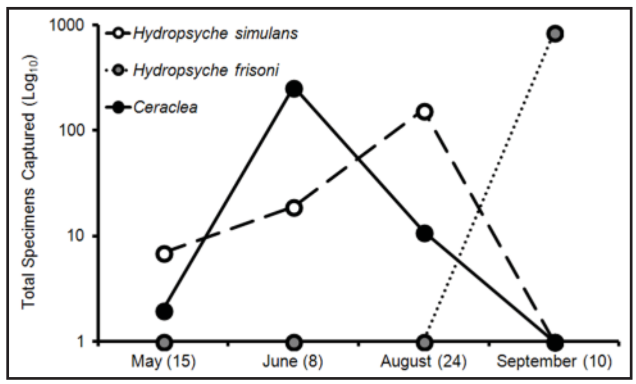

Figure 3: Abundance trends across months for major taxa of Trichoptera captured in blacklight traps at Mammoth Cave National Park, 2010-2011. Numbers of trap-nights for months are in parentheses.

Ceraclea spp. (Leptoceridae) was generally observed, but 252 specimens were captured at a mixed deciduous-dominant / coniferous site on 29 June 2011. The majority (n = 87) of these specimens that could be identified to species level were *Ceraclea flava* (Banks). Single specimens were also identified as *Ceraclea enodis* Whitlock and Morse and *Ceraclea maculata* (Banks) on that night. *Hydropsyche* species were variable in their occurrence across surveys. *Hydropsyche simulans* Ross was the most commonly captured species during May and June (albeit at low levels) and peaked in abundance during August. In contrast, Hydropsyche frisoni Ross was extremely abundant in multiple (n = 8) traps on 6 September 2010.

Discussion

This study increases our understanding of what invertebrate fauna are specific to MCNP over the growing season and also demonstrates that adult Trichoptera may occupy terrestrial habitats located away from aquatic environments. The relative richness of Leptoceridae peaked during the middle of the growing season while richness of Hydropsychidae remained more constant across our surveys. Less common families were either limited in their capture period or, as in the case of Phryganeidae, were dramatically more abundant during certain months (late summer to fall). Collectively, these data demonstrate shifts in the richness and abundance of taxa within the assemblage across a forest landscape. These seasonal records will facilitate targeted collection efforts in the future for specific taxa within the region.

While adult Trichoptera are typically most abundant near aquatic habitats (Petersen et al. 2004), broad terrestrial movement of these and other semi-aquatic insects is an integral component of their ecology that merits further study (Briers and Gee 2004, Didham et al. 2012). In most cases (n = 51 of 57 trap-nights) our surveys were conducted >100 m away from permanent water sources and riparian habitats, where larvae are found and where sampling for terrestrial adults typically takes place (Floyd et al. 2012). In this way, our study has also provided a unique survey of terrestrial habitats at MCNP and it has demonstrated that adult Trichoptera can be abundant in terrestrial ecosystems away from permanent water sources.

Acknowledgements

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Table 1: A checklist of Trichoptera collected in blacklight traps at Mammoth Cave National Park, 2010-2011. Records are stratified across months, with habitats reported where species were captured: mixed coniferous-dominant / deciduous forest (CD), mixed deciduous-dominant / coniferous forest (DC), mesic floodplain deciduous forest (F), and mesic deciduous upland forest (U). Taxa represented by a single specimen are denoted by an asterisk. Species representing new county records (following details of Floyd et al. 2012) are denoted by "†".

Taxon	May	June	August	September
GOERIDAE				
Goera stylata Ross	CD, U			
HYDROPSYCHIDAE				
Ceratopsyche / Hydropsyche sp.		DC	CD, U	
Cheumatopsyche sp.	CD, DC, F, U	DC		
Cheumatopsyche analis (Banks)	CD, DC,	DC		CD
Cheumatopsyche campyla Ross	CD, DC,		CD, DC	CD
Cheumatopsyche pasella Ross	CD, DC, F, U	DC, U		CD, DC
Diplectrona modesta Banks		CD, U	CD	U
Hydropsyche aerata Ross*†				DC
Hydropsyche alvata Denning	F	CD, DC, U	CD, DC	DC
Hydropsyche betteni Ross			CD	U
Hydropsyche frisoni Ross			DC	CD, DC, U
Hydropsyche orris Ross*	DC			
Hydropsyche phalerata Hagen*			DC	
Hydropsyche rossi Flint, Voshell, & Parker†		CD, U	DC	
Hydropsyche simulans Ross	CD, DC, F	CD, DC	CD, DC, U	
HYDROPTILIDAE				
Hydroptilid sp. *	CD			
LEPIDOSTOMATIDAE				
Lepidostoma sp.	F, U			
Lepidostoma griseum (Banks)* †				U
Lepidostoma togatum (Hagen)	CD, U			
LEPTOCERIDAE				
Ceraclea sp.	DC, U	DC	DC	
Ceraclea enodis Whitlock & Morse		DC	CD, DC	
Ceraclea flava (Banks)		CD, DC, U		
Ceraclea maculata (Banks)*		DC		
Ceraclea transversa (Hagen)*			DC	
Leptocerus americanus (Banks)*	DC			

Table 1: Continued

Taxon	May	June	August	September
Nectopsyche sp.		DC	DC	
Nectopsyche exquisita (Walker)*		DC		
Nectopsyche pavida (Hagen)*		DC		
Oecetis avara (Banks)* †			DC	
Oecetis cinerascens (Hagen)			DC	CD, U
Oecetis ditissa Ross			CD, DC, U	CD, DC, U
Oecetis inconspicua (Walker)	CD, DC, U	DC, U	CD, DC, U	CD, DC, U
Oecetis nocturna Ross			CD, DC, U	CD, DC, U
Oecetis persimilis (Banks)	F	U	CD, DC	CD, DC
Setodes incertus (Walker)		DC	CD, DC	
Triaenodes sp.	DC	U	CD, DC	
Triaenodes tardus Milne*	CD			
LIMNEPHILIDAE				
Pseudostenophylax uniformis (Betten) †	U			
Pycnopsyche antica (Walker)			CD	U
Pycnopsyche guttifer (Walker)				U
MOLANNIDAE				
Molanna blenda Sibley			CD	CD, U
PHILOPOTAMIDAE				
Chimarra sp.	DC, U	U	DC, U	
Chimarra aterrima Hagen*				CD
Chimarra obscura (Walker)	U		DC, U	
Dolophilodes distincta (Walker)	F		U	
PHRYGANEIDAE				
Agrypnia vestita (Walker)		U	CD, U	CD, DC, U
Phryganea sayi Milne			CD, DC, U	
POLYCENTROPODIDAE				
Polycentropodid sp.	U	DC, U	CD, U	
Polycentropus centralis Banks	U		DC	CD
Polycentropus cinereus Hagen*		DC		
Polycentropus crassicornis Walker*	DC			
RHYACOPHILIDAE				
Rhyacophila parantra Ross*				CD

Using LiDAR to Link Forest Canopy Structure with Bat Activity and Insect Occurrence: Preliminary Findings

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Abstract

Bats are an imperiled, yet ecologically-important group of vertebrate predators. Our ongoing research focuses on testing hypotheses about the relationships between the effects of fire on canopy structure and insect prey availability, and how these factors relate to use of foraging space by bats during the pre- and post-hibernation periods at Mammoth Cave National Park (MCNP). LiDAR-derived data (October 2010) were intersected with spatially explicit sampling of bat and insect populations (2010-2011) in order to characterize relationships between canopy structure, insect abundance, and bat activity. A canonical correspondence analysis for bat data suggested that forest canopy structure has a strong relationship with bat activity, particularly for species that echolocate at higher frequencies. Less variation was accounted for in a canonical correspondence analysis of insect occurrence. Even so, this analysis still demonstrated that variation in forest canopy structure influences the insect community at MCNP, albeit in varied ways for specific orders of insects.

Introduction

Remote sensing techniques such as light-detection and ranging (LiDAR) have expanded the scale and scope of ecological studies, allowing for more effective management of an expanding number of wildlife species (Vierling et al. 2008, Hudak et al. 2009). As bats are an imperiled and ecologically-important group of vertebrate predators, our study was initiated to relate the relative activity of these predators with the occurrence of their insect prey across the gradient of forest conditions found at Mammoth Cave National Park (MCNP). This ongoing project focuses on testing hypotheses about the relationships between the effects of fire on insect prey availability and canopy structure, and how these factors relate to use of foraging space by bats during the pre- and post-hibernation periods at MCNP. Aboveground habitat quality pre- and post-hibernation is critical because bats must go into hibernation with sufficient fat reserves and often leave hibernation in poor condition. A better understanding of the spatial and temporal patterns associated with bat foraging is important given the recent arrival of White-nose Syndrome (WNS) at MCNP.

Methods

Mammoth Cave National Park encompasses 23,000 ha in Barren, Hart, and Edmonson counties on the edge of the Crawford-Mammoth Cave Uplands of the Interior Plateau of Kentucky (Woods et al. 2002). We developed three-dimensional canopy height models across the entirety of MCNP in October of 2010 using discrete-return scanning LiDAR (>4 pulses / m^2). We processed these data using “Toolbox for LiDAR data Filtering and Forest studies” software (Chen et al. 2007). The output from this processing included high resolution digital elevation models, canopy height models, as well as three-dimensional canopy height profiles (Skowronski et al. 2007). These canopy height profiles allowed assessment of the density of vegetation throughout the forest canopy (Figure 1).

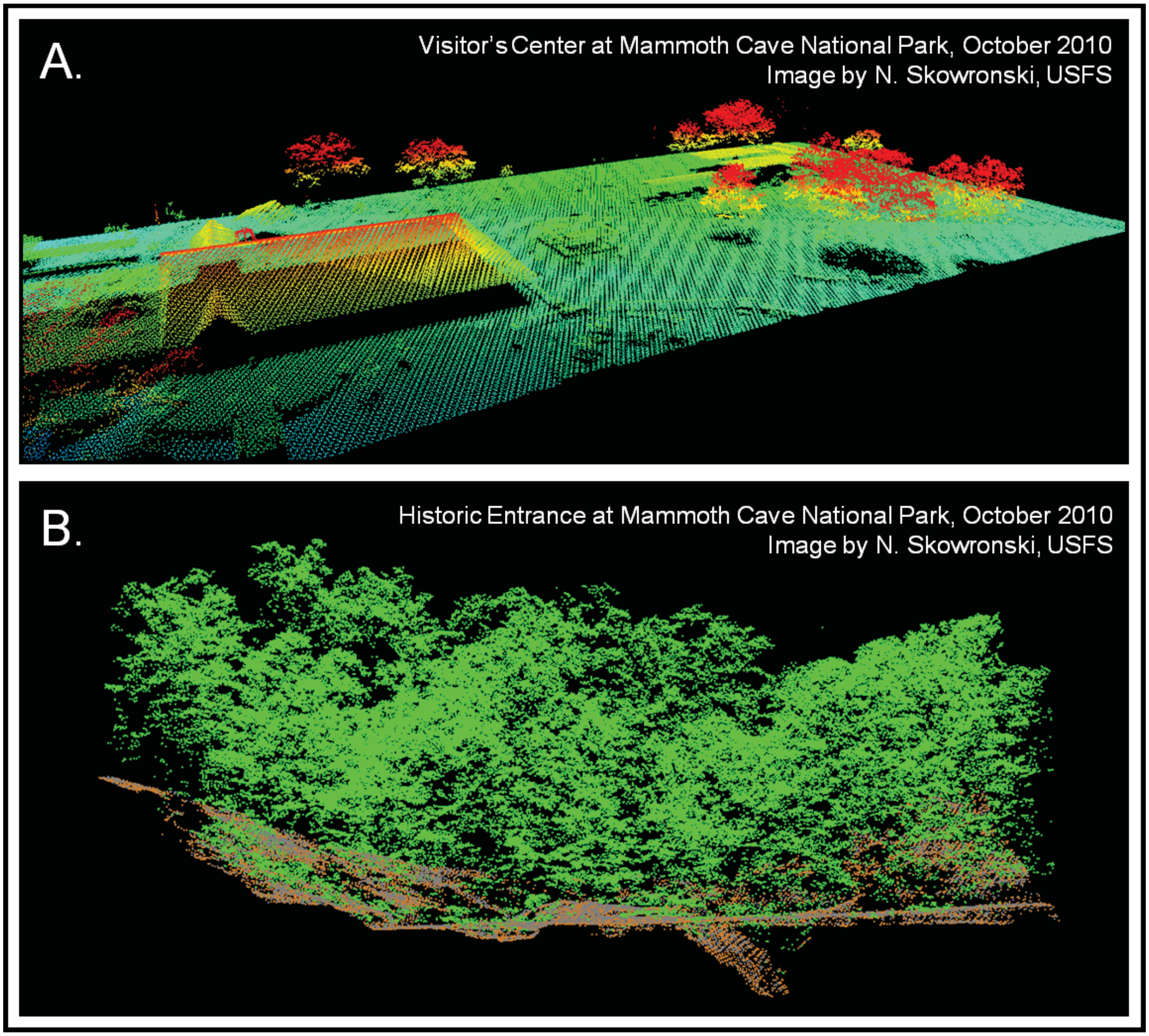

Figure 1: LiDAR-derived images demonstrating three-dimensional data derived for Mammoth Cave National Park.

LiDAR-derived data were intersected with spatially explicit sampling of bat and insect populations in order to characterize relationships between canopy structure, insect occurrence, and bat activity. We conducted surveys for bat activity and nocturnal insect occurrence from September 2010 through October 2011 using acoustic detectors and blacklight traps, respectively. These surveys took place across an array of upland and riverine habitats that covered a range of forest canopy heights. Transects were used for both techniques, which entailed multiple survey points (all ≥ 100 m apart). We surveyed transects in tandem so that monitoring took place at a burned land parcel simultaneous with an unburned land parcel.

We assessed bat activity using the Anabat II system (Titley Electronics, Colombia, Missouri) powered by a 12 V gel-cell battery and housed in plastic containers to protect equipment from inclement weather (O'Ferrell 1998). Acoustic surveys spanned multiple (2-3) nights to account for nightly variation (n = 4 acoustic detectors / transect). Despite standard placement and operation, the potential existed for microphone sensitivity to vary over time, as well as between units, so we regularly calibrated acoustic detectors using an ultrasonic insect repeller (Britzke 2004). Analysis of acoustic data collected between sunset and sunrise was carried out using Echoclass v.1.1, an automated software package for acoustic identification developed by the U.S. Army Engineer Research and Development Center and provided by the U.S. Fish and Wildlife Service (USFWS 2012). With this software, echolocation pulses are isolated into high frequency (> 34 kHz) and low frequency (≤ 34 kHz) categories (E. Britzke, U.S. Army Engineer Research and Development Center, pers. comm.). The resulting response variables we considered for bat activity were the numbers of echolocation files and pulses within the high and low-frequency categories, on a per night basis. The number of feeding buzzes isolated per night from echolocation data was considered as an additional response variable indicative of foraging activity by bats.

We assessed insect occurrence using 10-W blacklight traps (Universal Light Trap, Bioquip Products, Gardena, California). A single survey night for insects was conducted in the same land parcels as that for concurrent acoustic surveys (n = 4 traps / transect). As per recommendations of Yela and Holyoak (1997) for sampling Lepidoptera, survey were conducted on nights with temperatures ≥ 16° C at sunset, no precipitation, and low wind speeds. We suspended blacklight traps 2.5-m aboveground prior to sunset and operated traps throughout the entire night. A dichlorvos-based 'pest strip' (ca. 2×6-cm) was placed within each blacklight trap to subdue specimens. Insects were identified using keys (Covell 2005, Triplehorn and Johnson 2005) and reference collections at the University of Kentucky. Insects ≥10 mm in length were identified to the lowest taxon practical. Response variables were numbers per night for the most abundant orders we recorded: Coleoptera, Diptera, Hemiptera, Hymenoptera, and Lepidoptera.

We used canonical correspondence analysis (CCA) to explore relationships between forest canopy structure and bats and insects separately. Variables describing density of vegetation throughout the forest canopy follow those developed by Lesak et al. (2011) and were based on a 15-m radius around each faunal survey point. These forest canopy variables describe the relative density of vegetation in the understory, midstory, and overstory (referred to as "canopy" in Lesak et al. 2011), and the relative proportions of these strata in relation to one another (i.e., ratios of midstory to overstory, understory to midstory, and understory to overstory). We generated a gap index for each faunal survey point; this variable was a proportional expression of the absence of vegetation >3 m in height. This index thus considered the lack of taller vegetation (or "gap") within a 15-m radius around each faunal sampling point. Data were analyzed in PC-ORD v.4.25 following standard ordination techniques (McCune and Grace 2002) using default settings; Monte Carlo tests of significance were run for 300 iterations. Relationships within and between faunal and LiDAR-derived data were explored using biplots.

Results

Bat surveys were carried out over 114 nights during August-October of 2010 and April-October of 2011, yielding a total of 769 detector-nights. These data were collected prior to the detection of WNS at MCNP. The CCA of bat activity with forest canopy structure was significant (Table 1), and explained over 47% of the variation in acoustic data. High-frequency

Table 1: Summary of canonical correspondence analyses relating both bat activity and insect occurrence to forest canopy variables for Mammoth Cave National Park.

Summary Statistic	Bat CCA	Insect CCA
Total Variance ("Inertia") of Response Variables	0.82	1.03
Eigenvalue for First Axis	**0.390**	**0.108**
Variance Explained by First Axis (%)	47.4	10.5
Monte-Carlo Test of Correlations in First Axis (P-value)	0.001	0.05
Eigenvalue for Second Axis	**0.002**	**0.022**
Variance Explained by Second Axis (%)	0.3	2.1
Monte-Carlo Test of Correlations in Second Axis (P-value)	0.10	0.61

and low-frequency variables were broadly separated in multivariate space (Figure 2). A closer association was observed between the high frequency variables than between the low frequency variables. Variation in high frequency variables was more closely associated with variation of forest canopy variables than was variation in low frequency variables. The proportion of overstory, proportion of midstory, and gap index had the strongest relationships with bat activity. In contrast, the ratio of understory to overstory strata had the weakest relationship. High frequency bat activity was positively associated with an increased proportion of vegetation density in the overstory and midstory. Low frequency bat activity was less associated with forest canopy variables; however, low frequency pulses closely aligned with gap index, indicating a weak positive association between these variables. The incidence of feeding buzzes did not have a strong association with forest canopy variables.

Insect surveys were carried out over 41 nights concurrent with acoustic surveys, yielding a total of 205 trap-nights. The CCA of insect occurrence with forest canopy structure was significant (Table 1), and explained over 10% of the variation in the insect data. Abundance of various insect orders separated out in multivariate space (Figure 3). Abundance of Diptera and

Figure 2: A biplot based on a canonical correspondence analysis of bat activity and forest canopy variables for Mammoth Cave National Park (using LC scores). The ordination shows the relative relationships between bat activity variables (circles) and forest canopy variables (vectors). Abbreviated forest canopy variables are: gap index (gap), relative proportion of midstory (mid), relative proportion of overstory (over), relative proportion of understory (under), ratio of relative proportion of midstory to relative proportion of overstory (mid:over), ratio of relative proportion of understory to relative proportion of midstory (under:mid), and ratio of the relative proportion of understory to relative proportion of overstory (under:over).

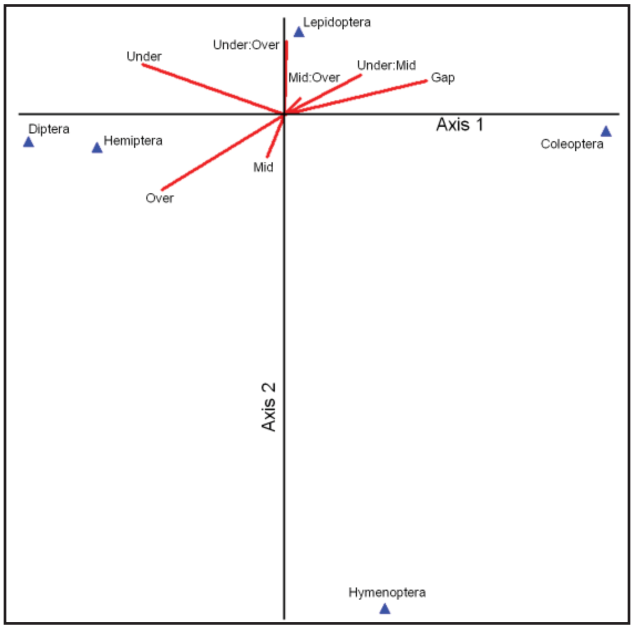

Figure 3: A biplot based on a canonical correspondence analysis of insect abundance and forest canopy variables for Mammoth Cave National Park (using LC scores). The ordination shows the relative relationships between insect abundance variables (triangles) and forest canopy variables (vectors). Abbreviated forest canopy variables are: gap index (gap), relative proportion of midstory (mid), relative proportion of overstory (over), relative proportion of understory (under), ratio of relative proportion of midstory to relative proportion of overstory (mid:over), ratio of relative proportion of understory to relative proportion of midstory (under:mid), and ratio of the relative proportion of understory to relative proportion of overstory (under:over).

Hemiptera were closely associated with one another and separate from abundance of Coleoptera and abundance of Lepidoptera. The latter two orders were also separated from one another. Abundance of Hymenoptera was widely separated from other variables, and consequently had little weight on the analysis. The proportion of understory, proportion of overstory, and gap index had the strongest relationships with insect abundance, whereas the ratio of midstory to overstory strata had the weakest relationship. Abundance of Diptera and Hemiptera were positively associated with an increased proportion of vegetation density in both the overstory and understory. Abundance of Coleoptera was distantly associated with gap index. Abundance of Lepidoptera was less associated with the first axis, but closely aligned with the ratio of understory to overstory strata.

Discussion

These analyses are a first step towards elucidating the role that forest canopy structure plays in determining aboveground habitat use by bats at MCNP. Our data suggest that forest structure has a strong relationship with bat activity, particularly for species that echolocate at higher frequencies. This finding largely agrees with observations that show bats that echolocate at higher frequencies tend to be more capable of flight in "cluttered" habitats that possess an increased density of vegetation (Barclay and Brigham 1991, Swartz et al. 2003). Conversely, we found a reduced association between low frequency bat activity and forest canopy variables. This outcome is consistent with the use of open "uncluttered" foraging space by low-frequency echolocating bats in other habitats (Aldridge and Rautenbach 1987, Saunders and Barclay 1992), and with data that demonstrate North American bats which use low frequency echolocation also possess wing morphologies suited for flight in habitats with decreased clutter (Bogdanowicz et al. 1999, Lacki et al. 2007). The association we observed between low frequency bat activity and an increased gap index, while weak, further supports these patterns in habitat use.

While less variation was accounted for in the CCA of insect occurrence, those data still demonstrate that variation in forest canopy structure influences the insect community at MCNP. Multiple insect orders were positively related with an increased density of vegetation in the understory strata (Diptera, Hemiptera, and Lepidoptera). The associations between specific insect orders and canopy conditions are complex, however, given: 1) the ordination positions of forest canopy variables relating to the upper strata, and 2) the wide ecological and taxonomic diversity seen across these common insect orders. Regardless, affiliations between insect groups and specific strata in the forest canopy likely relates to varied abundance and utilization of host resources (Ober and Hayes 2008, Dodd et al. 2012). The orders of prey most consistently consumed by North American bats (Coleoptera, Diptera, and Lepidoptera; Lacki et al. 2007) separated from one another in our ordination. This suggests broad differences in forest canopy conditions where these insect orders are most common. Since the relative consumption of these orders of prey does vary across bat species, it will be important to determine in future analyses whether any affiliations between insects and cluttered foraging spaces may translate to increased availability of preferred prey for specific species groups of bats (i.e., those tending to use either high or low frequency echolocation).

Despite the link between cluttered forest canopies and high frequency bat activity, we did not see a strong association between feeding buzzes and any forest canopy variable. We offer several possible explanations. First, high-frequency bats may actively move through cluttered space, but may not feed extensively in these canopy conditions due to reduced foraging success (Bogdanowicz et al. 1999, Swartz et al. 2003). Second, some high-frequency bats (i.e., the northern myotis, *Myotis septentrionalis*), are capable of feeding in cluttered habitats by gleaning insects from the surface of vegetation, where feeding activity is based on insects located by passive listening and not echolocation (Faure et al. 1993, Ratcliffe and Dawson 2003). Third, the feeding buzz variable considered in our analysis incorporated both high and low frequency echolocation pulses. Thus, potential relationships between forest canopy variables and a variable representing foraging success for bats that echolocate at either high or low frequencies may have been masked. Regardless, our findings indicate that forest canopy structure influences activity of bats. The extent to which feeding behavior of insectivorous bats is influenced by canopy structure, however, remains less clear. Based on our findings we postulate that canopy structure may be of less importance for feeding success of insectivorous bats than previously hypothesized (Hayes and Loeb 2007). Further studies are needed to confirm or refute this possibility.

Acknowledgements

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Monitoring Cave Bats at Mammoth Cave National Park

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Abstract

Cave-roosting bats are important to the nutrient-poor cave ecosystem because they import organic material which supports a specialized cave invertebrate community. Nine of thirteen bat species found at Mammoth Cave National Park are generally associated with caves at some time of the year. Two of the species that inhabit park caves are on the Federal Endangered Species List: gray bat (*Myotis grisescens*) and Indiana bat (*M. sodalis*). Regular population monitoring of hibernating endangered bats has occurred in a few park caves since the early 1980s. Since the early 2000s, cave bat monitoring on the park has expanded to include additional caves, species, seasons, and methods. On-park bat population trends are declining for some species, increasing for others, and stable for additional species. The need to regularly obtain reliable information on cave bat populations is underscored, since white-nose syndrome potentially threatens all of the cave-using species in the park.

Mercury Analysis in Rafinesque's Big-eared Bat Populations

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Abstract
Mercury (Hg) from atmospheric deposition from coal-burning power plants and other anthropogenic sources was analyzed in Rafinesque's big-eared bats from Mammoth Cave National Park. The mercury from water progressively moves up the food chain through insects, and eventually into bats. In 2011, 58 bats were collected and hair samples were taken for an analysis. The AMA254 Mercury Analyzer was used to determine the mercury concentration from the bat hair in parts per million. A considerable amount of mercury was discovered in the bats analyzed. The mercury concentration of juvenile Rafinesque's big-eared bats averaged between 0.5-1.0 ppm. Mercury levels in adult Rafinesque's big-eared bats averaged between 1.0-2.0 ppm, with female bats overall containing the highest amount of mercury. Notably, the mass and forearm length of Rafinesque's big-eared bats do not appear to affect the amount of mercury the bats contain.

Inventory of Terrestrial Wild Mammals at Mammoth Cave National Park: 2005-2010

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Abstract

An inventory aimed at documenting the occurrence of at least 90% of the terrestrial wild mammal species potentially present on Mammoth Cave National Park took place from 2005 to 2010. Documentation of mammal occurrence was accomplished via visual encounters and trapping. Visual encounters included methods like sighting individuals, conducting spotlight surveys by boat, locating mammal sign, hearing mammal calls, and finding dead individuals. A variety of trapping methods were used, including remote "trail" cameras, live traps, pitfall traps, drift fence-pitfall arrays, and several other opportunistic capture methods. 663 mammal records were documented by visual encounter or some trapping method representing six orders, 13 families, and 32 species. Of the 37 species potentially present in 2005, 32 species (87%) were confirmed present in 2010. Total trapping effort (# of trap-nights) was 118,567. A total of 163 specimens were collected as vouchers. No federally listed species of terrestrial wild mammals were documented.

Evaluating Interactions Between River Otters and Muskrats at Bridge Crossings in Kentucky

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Abstract

Muskrats (*Ondatra zibethicus*) prey on freshwater mussels in the Green River within Mammoth Cave National Park (MACA), many species of which are threatened or endangered. Reportedly, muskrat populations have been reduced in some streams where North American river otters (*Lontra canadensis*) were reintroduced and it has been suggested that river otter reintroduction at MACA might help conserve endangered mussels. To test that idea, we used occupancy estimation methods to evaluate the ecological relationship between muskrats and otters by collecting presence/absence data based on field sign found at bridge crossings in eastern and central Kentucky. Mean detection (p) and occupancy probabilities (ψ) for muskrats were 0.692 (SE = 0.045) and 0.723 (SE = 0.071) and for otters were 0.623 (SE = 0.036) and 0.662 (SE = 0.069), respectively. Otter occupancy was related negatively to distance from release sites, which suggests that the otter population is still expanding its range. A 2-species interaction model indicated that the occupancy by muskrats and river otters was independent, and we conclude that river otter reintroduction would not be an effective strategy for conserving mussels at MACA.

MAPS (Monitoring Avian Productivity and Survivorship)

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What is MAPS?

The Monitoring Avian Productivity and Survivorship (MAPS) Program comprises a continent-wide network of hundreds of constant-effort mist netting stations. Analyses of the resulting banding data provide critical information relating to the ecology, conservation, and management of North American landbird populations, and the factors responsible for changes in their populations. MAPS is coordinated by the Institute for Bird Populations which also conducts winter monitoring programs MoSI (Monitoreo de Sobrevivencia Invernal) in the Neotropics & MAWS (Monitoring Avian Winter Survival) program in temperate North America.

How do we conduct MAPS?

At our station there are 10 nets that we set up at sunrise, run the nets every 45 minutes for six hours, then do it again seven more times during the summer months. After capture, the bird is bagged & taken to the central station where processing occurs. Initially we have to identify the bird (Table 1). This tells us what size band to place on the birds leg. After banding occurs aging, sexing, wing measure, then weighing before release. Documenting all the criteria used to collect the data is entered into an IBP database for analysis & comparisons with other stations.

What have we learned?

Above all we are still learning. But what we have learned is that breeding and survival of birds vary more than we thought possible. Broadscale data on landbird productivity and survivorship are not available from any other monitoring program in North America, and while trend information is useful for determining which species are most in need of conservation efforts, information on vital rates as obtained from MAPS is important in determining which conservation actions are likely to be most successful and where they should be applied. This is critical for migratory species as factors affecting productivity and survival largely act at differing times of the year and in very distinct geographic areas. It has also been concluded MAPS data are vital in understanding the consequences of climate change on birds. National Parks, such as Mammoth Cave, provide ideal and much needed “control sites” for monitoring because large scale global and regional change patterns are typically not confounded by localized land use changes.

Table 1: Birds captured at Mammoth Cave National Park MAPS station.

Species	# of birds
Common Yellow-Throat	140
Kentucky Warbler	121
Indigo Bunting	97
Carolina Wren	95
Worm-Eating Warbler	85
Ovenbird	45
Northern Cardinal	40
Hooded Warbler	30
Red-Eyed Vireo	21
Wood Thrush	22
Tufted Titmouse	16
Acadian Flycatcher	15
Louisiana Waterthrush	15
Downy Woodpecker	11
Carolina Chickadee	10
Black & White Warbler	6
Scarlet Tanager	5
Prairie Warbler	3
Northern Parula	3
Blue Wing Warbler	2
Cerulean Warbler	2
White Breasted Nut	2
White-Eyed Vireo	2
Eastern Tohee	2
Ruby-Throated Hummingbird	2
Swainson's Thrush	2
Blue Jay	2
Veery	1
Yellow-Breasted Chat	1
Yellow-Billed Cuckoo	1
Yellow-Throated Warbler	1
Blue Gray Gnatcatcher	1

Breeding Bird Survey Summary from Mammoth Cave National Park, 1995 - 2012

Steve Kistler

Abstract

Breeding bird surveys are used by ornithologists to study the variations in bird populations across the United States and Canada. Initiated in 1966, the surveys were originally created by Chandler Robbins and colleagues to study the effects of pesticide use on bird populations.

Today, these data are used to monitor changes in avian populations due to habitat loss, habitat fragmentation, land-use changes, and chemical contamination. The administration of these surveys is jointly run by the US Geological Survey and the Canadian Wildlife Service. Almost fifty years of continuous surveying also provides excellent baseline data which can be used to determine the effects of man-made and natural environmental disasters, such as storms and oil spills.

Methodology

Today, there are approximately 4100 survey routes across the United States and Canada. Each survey route is run one day each year, during the time of year when breeding birds are singing on territory. In Kentucky, this period occurs between late May and late June.

Each route consists of fifty 3-minute stops, during which the observer records all birds heard or seen. No human calls or recording devices may be used to attract or disturb birds. The observer begins the route 30 minutes before local sunrise and stops at the same locations every year. Typically a route will take between four and five hours to complete.

Data handling

Raw data is entered in to the North American Breeding Bird Survey website, found at https://www.pwrc.usgs.gov/BBS/. Biologists at Patuxent Wildlife research Center in Maryland and at their Canadian counterpart post this information online for ornithologists to utilize.

Bird Study in Mammoth Cave N.P.

The large area of undisturbed habitat in Mammoth Cave National Park has been a favorite study site for Kentucky birders since the park's inception in 1941. Ornithologist Robert Mengel published *Birds of Kentucky* in 1965, the first book devoted entirely to the state's bird populations. Mengel, a professor at Western Kentucky University, devoted many years studying the birds of the Mammoth Cave region.

BBS data collection began in the park in 1966, when the first route in the park cut through the road from Lincoln to Brownsville on the north side of the Green River.

BBS routes run entirely within the boundaries of the park were initiated by the author in 1995. The first route established consists of fifty stops south of the Green River, and is simply known as the Mammoth Cave route.

A second route entirely north of the river was established with 33 stops in 1995. Known as Mammoth Cave North, it was expanded to include 50 stops in 2007. Due to difficult terrain and uncertain access to gated roads, all 50 stops have rarely been surveyed. For most of the years of this route's existence, it has consisted of thirty-three stops only.

Results

Data has not been collected consistently from the Mammoth Cave North Route over the years, so it will not be included in this summary. An informal review of Mammoth Cave North data reveals that it is very similar to data from the Mammoth Cave route throughout their shared history.

During the past eighteen years, fifty-six species of breeding birds have been recorded during BBS surveys. Other known breeders in the park have not been recorded on either route, either due to the fact that they are present in limited numbers, or that our routes do not pass through their preferred nesting sites. These include bald eagles, green herons, cerulean warblers, and others. A few species which are common in the open country outside the park may occur in very low numbers but not be observed using the BBS format.

The top ten most common breeding birds in the park are, in decreasing order, American crow (*Corvus brachyrhynchos*), red-eyed vireo (*Vireo olivaceus*), blue jay (*Cyanocitta cristata*), wood thrush (*Hylocichla mustelina*), scarlet tanager (*Piranga olivacea*), tufted titmouse (*Baeolophus bicolor*), ovenbird (*Seiurus aurocapilla*), Kentucky warbler (*Oporornis formosus*), Eastern wood-peewee (*Contopus virens*), and northern cardinal (*Cardinalis cardinalis*).

Table 1 shows the number of individuals of these species recorded each year from the fifty stops on the Mammoth Cave Route.

Population trends

The breeding bird surveys are most useful to determine increasing or decreasing bird populations. They are sampling methods only, and they do not purport to produce actual counts of the number of breeding birds in an area.

The data suggests that some populations fluctuate wildly within short periods of time. The author believes that most of these fluctuations are caused by vagaries of the sampling methods. Observations indicate that bird activity correlates strongly with weather conditions. A cool cloudy morning will produce fewer numbers of birds than a warm, sunny one. The morning following a cool rain event lasting more than one day may produce a flush of activity, as birds get out, feed, and resume nesting activities.

After forty-six years of continuous sampling, the BBS is valuable to us today as a source of long term population trends. The following four figures show population trends among groups of interest within the park.

Figure 1 shows the population trends for three common year-round park residents: tufted titmouse, red-bellied woodpecker, and northern cardinal. The wild fluctuations are typical for most of the bird species surveyed. Small passerines typically live three to five years, and variations in food sources or weather can affect them in the short term. The dip shown for all three species in 2008 correlates with the presence of seventeen-year cicada hatch. The insects were loud, and observers could not hear bird songs as well as they normally would. If anything, these trends move slightly upward, meaning the populations of these species in the park are stable or increasing somewhat.

Figure 2 shows the population trends for three common summer residents: red-eyed vireo, scarlet tanager, and ovenbird. These species typify most of the birds we see here in the park: those that only spend part of the year in Kentucky. The three species depicted here are neotropical migrants, i.e. they spend October through March in Central and South America. All of these live and nest in eastern deciduous

Table 1: These numbers represent the total number of individuals of the top ten species recorded on the Mammoth Cave Breeding Bird Survey route between 1995 and 2012.

Ten Most Common Mammoth Cave National Park Breeding birds, 1995 - 2012

Year	American crow	Red-eyed vireo	Blue jay	Wood thrush	Scarlet tanager	Tufted titmouse	Ovenbird	KY warbler	Eastern wood-peewee	Northern cardinal
1995	51	49	52	29	36	22	16	12	14	12
1996	51	45	29	25	50	35	5	25	5	14
1997	90	30	32	33	19	46	6	20	12	9
1998	71	35	26	20	29	45	9	25	13	8
1999	104	36	72	38	29	26	8	20	21	9
2000	53	44	27	23	37	37	20	22	20	12
2001	61	54	37	28	34	23	14	26	20	19
2002	85	37	40	33	25	31	21	28	20	16
2003	90	59	43	23	27	43	16	15	16	17
2004	53	38	19	27	26	21	26	28	21	15
2005	39	48	32	35	33	22	22	36	18	17
2006	77	44	35	29	31	27	25	29	12	21
2007	45	51	33	51	35	24	47	29	16	20
2008	8	24	14	26	17	29	28	10	17	11
2009	84	45	11	35	26	41	43	31	21	10
2010	39	43	21	43	34	25	41	18	26	15
2011	34	40	31	24	34	19	50	21	14	20
2012	24	38	17	34	29	31	31	14	16	18
TOTAL	**1059**	**760**	**571**	**556**	**551**	**547**	**428**	**409**	**302**	**263**

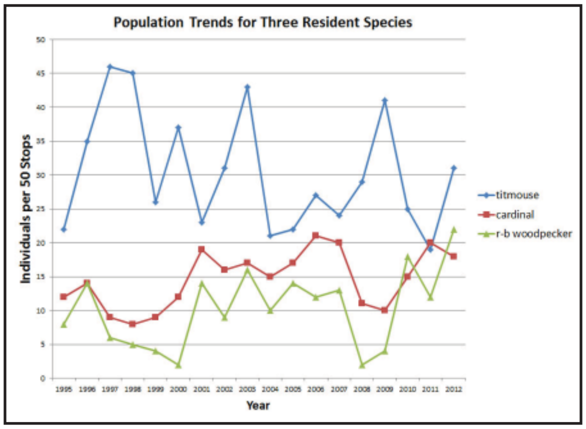

Figure 1: Populations trends for three year-round resident species.

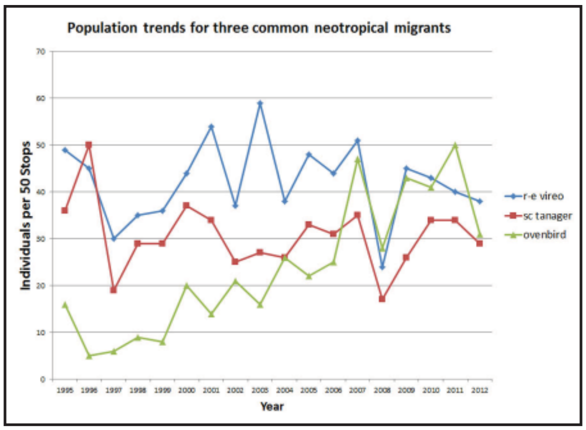

Figure 2: Population trends for three breeding bird species which winter in the tropics.

forests. Despite continuous logging and land development, habitat is still available in North America. Ornithologists and conservationists are concerned about habitat destruction in Latin America, where wide expanses of land are being deforested. So far, habitat loss has not affected these populations in the Mammoth Cave area. If anything, ovenbird numbers have increased steadily over the survey period. All three of these species were difficult to detect during the noisy spring of 2008.

Figure 3 shows the population trends for crows and blue jays. Starting about the year 2000, these species were subject to infection by West Nile virus, and they suffered widespread mortality across their ranges. Populations in the park fluctuate as do all other species, but their trend lines seem to be decreasing. Crows are often detected by their loud calls, which is reflected by their low numbers during the spring of 2008.

Figure 4 shows the population trend for wood thrushes. These birds are of great concern to ornithologists, as their numbers in the U.S. have declined almost fifty percent since surveys began in 1966. While their temperate habitat remains sufficient, they have suffered heavy habitat loss in their tropical homes. Mammoth Cave National Park is a haven for wood thrushes; their population densities are as high here as in almost any location in their U.S. range. Populations are stable.

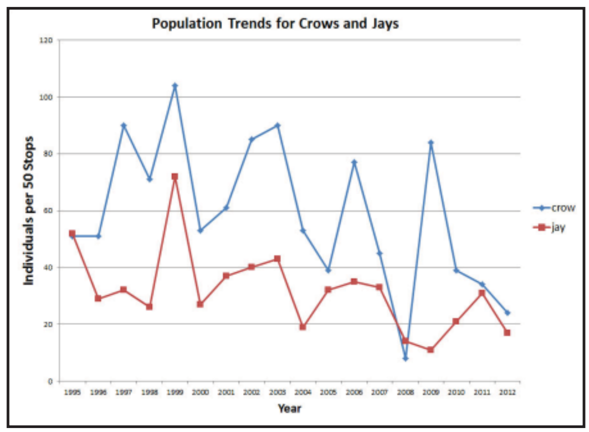

Figure 3: Population trends for two species reduced nationally by West Nile virus.

Conclusions

Breeding Bird Surveys are valuable for their ability to track long-range trends in bird populations. Bird numbers fluctuate greatly on an annual basis, but trends which are observed over longer periods are of higher significance to ornithologists.

Bird populations at Mammoth Cave National Park have been stable for the past eighteen breeding seasons. The park is a sanctuary for woodland species, such as ovenbirds, scarlet tanagers, and wood thrushes. Without interference from roads, development, and edge effects, these species continue to thrive in the park.

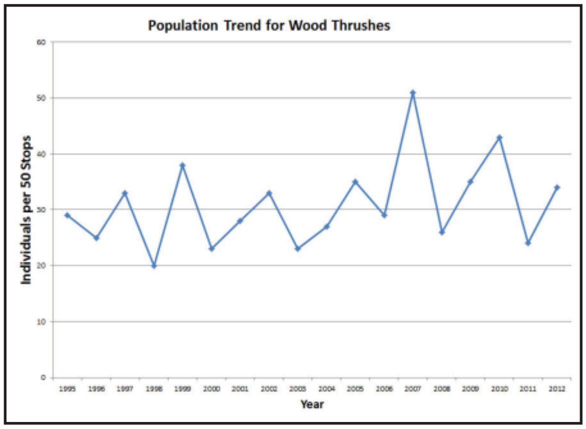

Figure 4: Population trends for wood thrushes at Mammoth Cave.

How Did Max Kämper and Ed Bishop Map Mammoth Cave?

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Abstract
Max Kämper made the first accurate map of Mammoth Cave showing approximately 35 miles of passages. His partner in surveying the cave was Ed Bishop, a capable caver and descendant of Stephen Bishop – the famous slave guide and explorer of Mammoth Cave. To be fair, Edmund Lee's 1835 map was a reasonably accurate rendering of the known cave at that time, which was only 8 miles. The map is a beautiful piece of cartography, but somehow he measured Mammoth Dome as being 280 feet deep, which would put it below the level of Green River. As well, Black Snake Avenue to Bottomless Pit is not shown correctly. We do not know in any detail how Max and Ed surveyed the cave so accurately. The purpose of this paper is to explore the possibilities and discuss the scant information available to us.

Introduction
Max Kämper of Berlin, Germany arrived at Mammoth Cave early in 1908, and stayed most of the year mapping the cave before returning home. Compared to New York City where he initially arrived, Mammoth Cave could only be considered remote except for one important fact: Max Eyth had visited Mammoth Cave in 1866 and drew a map of the cave. Max Eyth was a famous German engineer who had published a book in 1905 about many things including his work at Mammoth Cave (Binder 1997). Kliebhan and Thomas (2008) determined that this book was in the Kaemper family library and that Max Kämper would doubtlessly have read it. They concluded: "We do not have any doubt: Max Kaemper's journey to America was a journey on the footsteps of his idol Max Eyth, the famous engineer and poet, who's travel descriptions led the young engineer finally to the largest cave of the world." DeCroix (2008) and Sides (2008), who are also noted Kämper researchers, each concluded that Max's visit to Mammoth Cave was inspired by his famous predecessor, Max Eyth.

Over a period of only 8 months, Max Kämper made a highly accurate map of Mammoth Cave showing approximately 35 miles of passages, large and small. His partner in surveying the cave was Ed Bishop, a capable guide, caver, and relative of Stephen Bishop – the famous slave guide and explorer of Mammoth Cave. To be fair, Edmund Lee's 1835 map was a reasonably accurate rendering of the large passages known at that time, which was only 8 miles. The map is a beautiful piece of cartography, but somehow he measured Mammoth Dome as being 280 feet deep, which would put it below the level of Green River (Lee 1835). Continuing in the vein of fairness, no cave map is perfect, including Max's map. For instance, Henry's Dome and Dragon Pit are shown as different locations, but they are the same shaft. Dragon Pit especially is not easy to survey to, and errors in such gnarly passages are more likely. There were many previous mapping efforts, starting in 1810, and even beyond Max and Ed's time that showed Mammoth Cave less accurately (Brucker 2008). It should be noted that Stephen Bishop's map was drawn mostly from memory at Locust Grove near Louisville (Bullitt 1845). Realizing that, it could have been a useful schematic for getting around in Mammoth Cave, and far better than most anyone could draw from memory.

We do not know in any detail how Max and Ed surveyed the cave so accurately. We will explore the possibilities and discuss the scant information we have. How did they measure distance, bearings, and track vertical changes? These measurements are crucial to producing an accurate survey of the cave. If there is significant error in distance or inclination measurements, then the true horizontal distance or vertical extent calculated will be wrong. More obviously, if compass bearings have significant errors, then the direction a passage is shown to run will be wrong. Distance magnifies the effect of any compass bearing error, just as slight movements while aiming a rifle result in being much further off target in a long shot. We also do not know how Max recorded data in the cave or subsequently managed the data, but presumably trigonometric calculations were done by hand, slide rule, or possibly using logarithmic tables. We do know that Max managed to render a map that is still used today by park staff to show visitors, researchers and educational groups the basic lay of the Historic Section of Mammoth Cave.

In conversation with Dr. Dieter Mucke from Germany at the 2009 International Congress of Speleology in Texas, he indicated that the Deutsches Museum in Munich, Germany had extensive information on German survey and mining technology. He pointed out that surveys in mines needed to be very accurate, and that Max's training may have included such survey skills. Interestingly, Hovey (1909) reported that Max "…came from Germany to America to acquaint himself with American manufactures and mining methods…" On this advice from Dr. Mucke, Klaus Kämper, Ulrike Schönleber (Max's grandson and granddaughter), plus Colleen and Rick Olson went to the Deutsches Museum in September of 2009. We found that there were many sophisticated survey instruments that existed far prior to Max's time, and of course ones that were available to him in his day. With the foregoing discussion as background, let us consider each of the key elements of the survey: distance, bearing, and inclination or elevation change measurements.

Distance

Hovey (1909) reported that Max Kämper told him "…that the dimensions of the cavern were too great to warrant any general method of measurement other than pacing, to which he had been trained in the military service." Brucker and Watson (1976) discussed Max and Ed's survey techniques, and reported also that Max paced the distances. Bernd Kliebhan consulted Max Kämper's obituary and verified that Max spent a year of voluntary service in the Field Artillery Regiment 3 at Brandenburg. This was after passing his exam as an engineer in the autumn of 1905. Bernd indicated that survey methods would not have been part of his training as a mechanical engineer, but that it would have been an important part of artillery training. Pacing would potentially be useful for distance measurement in those passages with level trails or those with consistent slopes. However, even in passages that are fairly level and maybe had a somewhat developed trail, if that trail undulates then the distance paced will be greater that the direct line distance. In the rough breakdown-littered passages in much of the cave (such as Grand Avenue), pacing would yield gross errors in distance measurement that would not lead to the high accuracy of the final survey. Max also clearly took data on distance to the walls, and pacing would be even more difficult with these measurements due to uneven terrain.

In the same paper, Hovey describes a visit to Violet City in November of 1908. He states that "We found it an immense expanse, measuring by the tape line 250 feet in length and 125 feet in width…", which clearly indicates the use of a tape measure. Everybody learns how to survey caves in part by learning how not to do it, and Max was probably no exception. The entry for May 25, 1908 in Max's journal indicates that he gave 60 cents to Ed Bishop for string and a stick. While Klaus Kamper, Bernd Kliebhan, and Chuck DeCroix worked to translate Max's journal they wondered if the string and stick were used for surveying (Figure 1). String could easily be marked at intervals with knots for distance measurement, and this technique could have been used early in the mapping effort especially in small passages where pacing was not possible. The string may also have been used to suspend a special compass or clinometer. The string and stick were purchased only a week after his suitcase (probably a trunk) arrived by freight.

Bearing

Hovey indicated in his article that Max reported "He used a good surveyor's compass in the main cave and principal branches, but relied on a pocket compass for the narrower passages and crawlways." At the Deutsches Museum in Munich we found a display of mine survey methods showing the use of a string mounted compass (Figure 2). If Max used a string-mounted instrument, then the alignment between stations was not an issue: the string held tight between stations would have defined the survey line. This could, in part, account for the high accuracy of the survey. Another major factor is competence, and Max was apparently very good at taking instrument readings. Instrument reading blunders due to variable skill level in reading instruments have plagued Cave Research Foundation (CRF) surveys, so CRF instituted back-sight readings to catch mistakes in the field. The stick and string purchased from Ed Bishop may also have served a purpose in bearing measurements. In order for the compass needle to swing freely, the compass must be very close to level. However, survey stations are rarely level with each other. The stick could have been used to space up from the floor or down from the ceiling in order to take a compass bearing between stations.

For the smaller side passages, where a larger string-mounted compass would be impractical, there were more compact

Figure 1: Klaus Kämper, Bernd Kliebhan, and Chuck DeCroix puzzle over entries in Max Kämper's journal at the Olson home during the Kämper Centennial event in October 2008.

Figure 2: A mine survey display at the Deutsches Museum showing the use of a string mounted compass.

instruments available. At the Deutsches Museum we saw a compass with fold- up alidade type sights that dated from about 1890. This type of instrument was compact and yet accurate enough to serve Max's purposes.

With the impressive array of compasses and inclinometers available to Max in Germany, we wonder if he brought such instruments with him to Mammoth Cave? Kliebhan and Thomas (2008) determined that Max departed Berlin with 155 pounds of luggage, so he was not travelling light, and survey instruments of the type we have discussed here are not very heavy.

The discussion of possible compasses used leads to the question of what kind of light he used to read the instruments without magnetic interference problems. The scene in Figure 2 shows a brass lamp being used to illuminate the compass, but we don't know if Max had such a lamp. Olson (2008) speculated that Max and Ed may have used a carbide lamp, based upon an account of a trip to Cathedral Domes by Horace Hovey (1907). Once again, Hovey's 1909 article has proved illuminating because he said "Bishop carrying an automobile searchlight for the purpose, thus giving me my first view of the wonderful and fascinating region to which has been given the name of 'Violet City'…" Auto headlights in those days were most often acetylene lamps, and Hovey had his acetylene bicycle lamp along as well. With this type of lighting it would be possible to direct light down into the compass to read it, something impossible with the iron Mammoth Cave lamps that would have also caused magnetic interference. Finally, in a letter from Albert Covington Janin to the Mammoth Cave Estate dated June 1, 1908, he describes using a carbide hand lamp in Violet City (Janin 1908). Access was via the breakdown crawl that Max and Ed first entered by, so almost certainly Max and Ed were his guides. Carbide lamps would also make mapping a large trunk passage like Grand Avenue feasible, as this would be nearly impossible in the feeble glow of the traditional Mammoth Cave oil lamps. Candles would be a simple, nonmagnetic alternative for lighting the compass. Keeping the candle lit between shots would have been challenging, or perhaps it could have been relit with a match for each shot.

Inclination or Elevation Change

Curiously, Horace Hovey did not discuss measurement of inclination in his 1909 paper. One possibility is that Max and Ed did not take inclinations, and instead kept track of elevation changes. This could have been done with the aforementioned stick that Max purchased from Ed, assuming that length increments were marked on it. This could work well in fairly level passages, but surveying through the Corkscrew with 30 meters of vertical distance between Broadway and Bandit's Hall might require more sophisticated methods. Vertical shots can be very useful in a place like Corkscrew, but where that is not possible, high angle shots may be unavoidable, and in these situations a clinometer may work best. Figure 3 is a vertical profile of the Historic Entrance vicinity and shows many steep to vertical connections between levels. In early CRF surveys, inclinations were not taken. Instead (Olson remembers this) they estimated changes in elevation. Problems resulting from this method led to the adoption of vertical angle measurements when Suunto instruments became available. Hovey reported that Max "…had taken no barometric observations", so we can rule out this method, which is of doubtful precision under the best of circumstances.

In the mining section display at Deutsches Museum, one of the survey team members was holding a string–mounted inclinometer. This was a very reliable way to measure angles up and down. In the Visitor Center museum at Dachstein Mammuthöhle in Austria, we also saw an old string-mounted inclinometer on

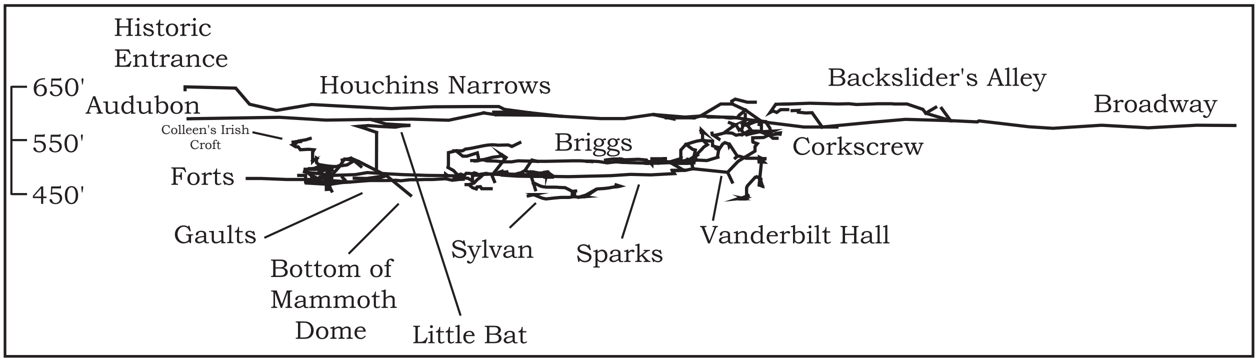

Figure 3: A vertical profile of the Historic Entrance area based upon modern survey data. Courtesy of Ed Klausner, CRF.

display, so these were perhaps not rare in Max's time. In the cartography section of the Deutsches Museum, we found two compact hand held inclinometers on display, so instruments of this type would also have been available to Max (Figure 4).

Survey Station Labeling

In order to avoid mistakes in reading from one station to the next, and especially for tying survey lines to each other, it is important to mark stations in some manner. In portions of the cave where Max and Ed surveyed, we had noticed stations marked in yellow and orange crayon. The station labels consisted of a number with a # sign, and in some places there were short wooden stakes. We wondered if these were Max and Ed's stations until we realized that this numbering system was used along the route from Roaring River to New Discovery by Park Engineer Paul McG. Miller and teams working under him in the late 1930s. To date, we do not know how Max and Ed Marked survey stations.

Accuracy Assessment

There were two primary ways for Max to assess the accuracy of their survey. First, were survey loops within the cave. When the survey line ties back into itself, ideally the tie stations will plot right on top of one another. As a practical matter this does not happen with compass surveys, and instead the hope is that the error is within reason. According to Max's journal, they mapped Gothic Avenue on March 11, Corkscrew on March 15, and Lost Avenue on March 19. The journal does not provide a complete record of mapping activity, so presumably the survey of Gothic Avenue was followed by Gratz Avenue and Wilson's Way, so that when Lost Avenue and Harvey's Way were surveyed, a loop was completed via Main Cave at Acute Angle to Booth's

Figure 4: Hand- held inclinometers from Germany were on display in the cartography section in the Deutsches Museum. The one shown was made in Munich around 1860, and with this instrument it would be possible to align the case along a string between stations or use the flip-up alidade sights.

Amphitheater. According to Max's Journal, he was at Annetta's Dome at the end of Gratz Avenue with Judge Janin on April 26, but it does not say they were mapping. In similar fashion, the Corkscrew survey would tie into the Historic Tour route above at Kentucky Cliffs and below at Bandit's Hall. On March 20 and 21 they mapped Fort's Way and Gault's Way off Mammoth Dome, and these passages would make a nice loop useful for accuracy assessment. An even bigger loop would have been Mammoth Dome and the end of Little Bat Avenue, which they knew connected. Other loops were certainly completed, but these were likely the earliest in the mapping effort and would have given Max an idea of how accurate the survey was and whether modifications to the survey methods were needed.

The second way for Max to check accuracy was via sound connections between different parts of the cave that the map showed to be close to each other. From the survey it was clear that Sandstone Avenue and Violet City were very close, but no previous maps indicated this proximity and the veracity of this was apparently questioned. In a letter to Judge Janin dated August 4, 1908, Max informs him that Violet City is 1.36 miles in a direct line from the hotel and that the end of Sandstone Avenue is 1.40 miles at a bearing of 26 degrees east of south (154°) without consideration of "declension" (declination) because he did not know what it would be in Kentucky. He finishes by saying "Every other statement is idle talk without any better proof than void guessing!" That these passages were indeed close was verified, probably on July 1 according to Max's journal entries, with Ed Bishop in Sandstone Avenue and Max with Norman Parrish in Violet City. According to Hovey (1909), they first fired revolvers, which were inaudible, and then pounded on the walls, which could be faintly heard. Hovey's short article also mentions two other sound connections. A pounding test was conducted where Wright's Rotunda crosses over Serpent Hall, and verified the accuracy of the map at that point. Finally, Hovey reported that "while we stood in Chief City, we plainly heard the steam cars running overhead along the Mammoth Cave Railroad." This would be a less informative test of accuracy due to the ability of the train sounds to travel farther than the sound generated by hand pounding. However, if Max ran a spray line off one of his surface survey lines to where Chief City was located according to his cave survey, then the proximity of the rail line to Chief City could have been demonstrated. Indeed, one of us (Toomey) pulled up the map showing Chief City and the overlying former rail line, and the two features are almost perfectly coincident along a north-south axis. Therefore, the rail line would have been most useful along an east-west axis for accuracy assessment.

A final possible way that they may have been able to check accuracy was the result of an unintended event. After pounding demonstrated the proximity of Sandstone Avenue and Violet City, they attempted to connect them by blasting on the Violet City side. They did not connect the two passages, but did come very close to reaching the surface (Hovey 1909, Meloy 1975). This surface site was known to Max and Ed, so they could have surveyed overland from the Historic Entrance to close a large survey loop. We do not know if they did this, but it is something that could have occurred to them, and we do know that they conducted surface surveys to ascertain how the cave and property lines related. Violet City is a long survey run from Historic Entrance, and so having another surface tie would be extremely attractive.

The modern CRF survey of Mammoth Cave has had the benefit of many decades of work and reworking of the map, many entrances that provide control points to detect significant errors, cave radio locations in passages remote from any entrances, computerized distribution of survey error, dozens of survey teams, and so on. Max did not have much time, and he had only one entrance plus one possible blast site with surface disturbance at Violet City that he and Ed could have used as an additional control point. With these facts in mind, we compared Max's map with the current CRF survey, and the results were really quite good as can be seen in Figure 5.

Scale and Orientation

No scale or north arrow was put on the map because it was for private use of the Mammoth Cave Estate, and in case the map should fall into the wrong hands then competitors could not easily tell which passages extended beyond estate property lines. However, in a December 7, 1908 note, Max provided this information in his own hand, written on stationery from the Raleigh Hotel in Washington DC. It is copied here in italics:

> ***Key to the Map of the Mammoth Cave.***
>
> *The arrow at the entrance points due South East. The little circle in the Rotunda shows the point where on surface is the corner in the angle of the Hotel. (Pinson's Office)*
>
> *From this point as a basis a due S.E. line is drawn, which forms an almost exact center line to the main course of the cave. This line is indicated by a sequence of little circles, ½ mile distant from each other, thus giving at the same time the scale of the map, which is 20 cm. to ½ m. The full –mile points are indicated by a small circle inside a slightly bigger circle (shown graphically in the note).*
>
> *1 mile point near "Burleys Way"*
>
> *2 " " " "Hell Hole"*
>
> *3 " " " "Blairs Dome"*

Conclusion

In summing up, we can say that Max Kämper's visit to Mammoth Cave was likely no accident and instead was inspired by the famous German engineer, Max Eyth, who had mapped Mammoth Cave and written about it in a book that Kämper almost certainly read. We know that underground survey techniques for mining in Germany were highly developed, and that there were an array of compact but accurate compasses and inclinometers available. Given that he was following in the footsteps of Max Eyth, Max Kämper may have brought suitable survey instruments with him. The question of distance measurement is somewhat confused by Hovey's report of pacing and also of the use of a measuring tape. The usefulness of pacing would have been limited to places with nearly planar floors, and where walking was possible. These criteria eliminate much of the cave Max and Ed surveyed. This problem would be manifest in both measuring distances from station to station, and also in measuring to the walls from a given station. We know that Max and Ed checked the accuracy of the map in at least two places: Wright's Rotunda/Serpent Hall, and Violet City/Sandstone Avenue. Blasting to connect these latter two passages may have given them another surface control point at Violet City in addition to the only other one: the Historic Entrance. Max Kämper's map compares favorably with the modern CRF map in the Violet City and Cleveland Avenue area.

Acknowledgements

Many thanks for review of the manuscript by CRF Chief Cartographer Bob Osburn, CRF Mammoth Ridge Cartographer Ed Klausner, Mammoth Cave Guide Chuck DeCroix, Mammoth Cave Exploration Historian Dr. Stan Sides, and last but not least, Mammoth Cave Guide Colleen O'Connor Olson.

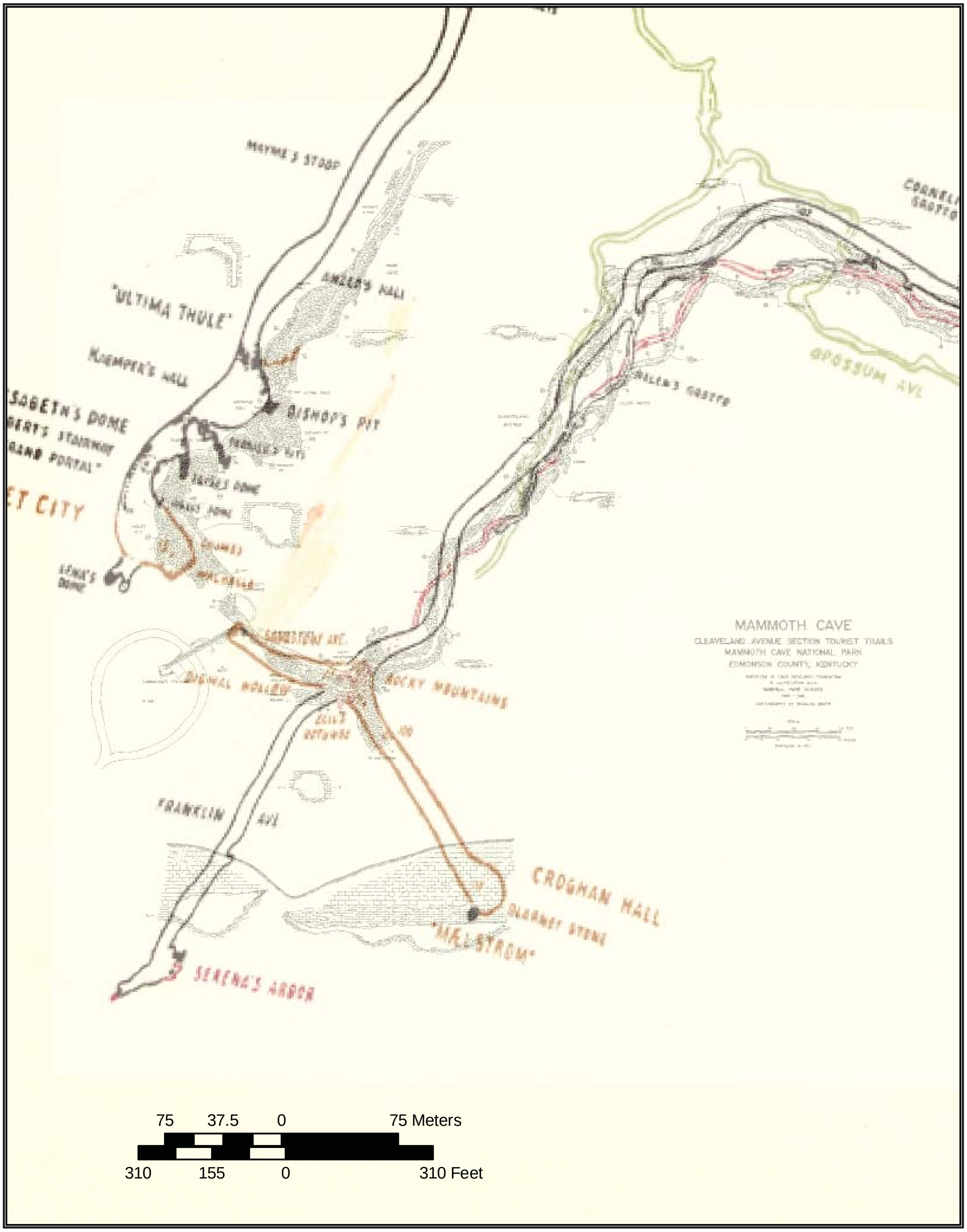

Figure 5: Overlay of Max Kämper's map on the current CRF map by Rick Toomey. Overlay was created in Arc View using only two registration points for the Kämper map: Historic Entrance (TT1WAZ) and Ste. Catharine City (TT7W).

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The Making of a Connection – The Potential of a Mammoth Cave System-Whigpistle Cave Connection

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Abstract

The current length of the Flint Ridge-Mammoth Cave System (to be called Mammoth Cave System for the rest of this paper) has been attained by a series of connections instigated by cave explorers/mappers of the Cave Research Foundation (CRF) and Central Kentucky Karst Coalition (CKKC). Between 1961 and 2011, connections have expanded the surveyed extent of the cave system to its current "official" length of 390 miles (650 km). Connections do not happen serendipitously; rather, systematic exploration is the key to successful connections. CRF and other groups working in the Mammoth Cave area have adopted a method of systematic exploration that involves mapping cave passages, correlating the surveyed cave passages and their elevations with topographic maps, aerial photographs, and elevation controls such as geographic surface benchmarks (Kambesis 2007). But most important is translating that data into cave maps projected onto topographic overlays. Cave maps and overlays reveal not only the extent of the cave system, but also invoke an understanding of the geological and hydrological conditions that control cave passage development and distribution (Kambesis 2007). Georeferenced cave maps along with geological and hydrological insight are what provide the perspective on cave connection potential and drives exploration objectives and priorities. Incorporating these data into a GIS system is proving to be a valuable exploration tool and one that is currently being used to work toward the next big connection to the Mammoth Cave System – that of Whigpistle Cave System. This paper focuses on the potentials toward making that next big connection and the work necessary to accomplish it.

Introduction

A section of the regional map of the Mammoth Cave area (Figure 1) shows the results of nearly 65 years of systematic cave exploration in the region. More than 585 miles (978 km) of cave passages have been explored and mapped not only within the Mammoth Cave System (with a length of 390 miles (650+km)), but in other caves located outside of Mammoth Cave National Park including Fisher Ridge Cave System at 119 miles (198 km), Whigpistle Cave System at 35 miles (58 km), Hidden River Complex at 21 miles (35 km), Crumps Spring Cave at 11 miles (18 km), James Cave at 10 miles (17 km) and Vinegar Ridge at 9 miles (15 km) (Gulden 2012). There are many smaller cave systems whose combined lengths with those of the larger caves approaches 650 miles (1000+ km) . Quinlan et al., (1983) suggested a potential of 1000 miles (1,600 km) of cave passages within the Mammoth Cave region. This potential has motivated cave explorers to pursue extending the known limits of the world's longest cave system.

The mode for continuing to expand the world's longest cave has been to seek connections with other nearby cave systems. Despite the great length attained by the Mammoth Cave System, connection potential is still viable with other large systems in the area. Though proximity of the passages of different cave systems hints at possible areas to connect, it is not the only, nor the most important criteria. Geological and hydrological conditions are

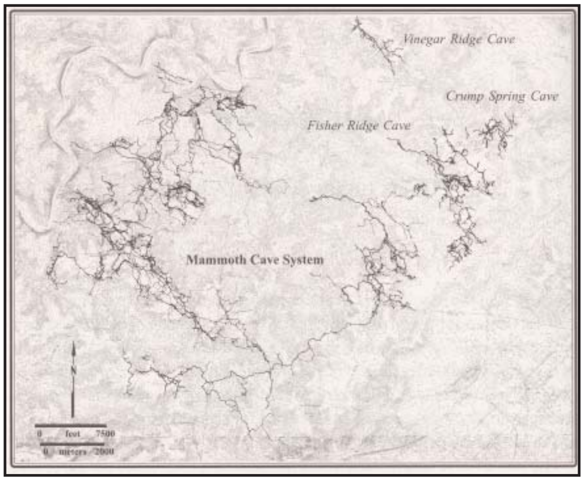

Figure 1: A section of the regional map of the Mammoth Cave area. From Borden and Brucker 2000

critical factors for determining viable areas in which to expend survey manpower and resources. For example, the Fisher Ridge Cave System is the next most extensive cave system in the Mammoth Cave region and comes within 300 feet (100 meters) of Mammoth Cave System. However, the areas of closest proximity between the two systems are located high in the ridges which are the least favorable spots for connection. Cave passages in high-ridge locations tend to be truncated by valley erosion which removes significant sections of previously connected passages. The best place to pursue connection is in the active, base-level streams that are still actively forming the caves. This is where connections have been made in the past and will likely continue to be made in the future. Of all of the known major caves in the Mammoth Cave area, Whigpistle Cave System holds the most promise for a future connection to the Mammoth Cave System.

The Potential for Connection

The GIS map shows that the Whigpistle Cave System is located a little more than a mile southeast of the Proctor section of Mammoth Cave System (Figure 2). Woolsey Valley, one of many erosional valleys on the Mammoth Cave plateau, occupies the gap between both systems. This means that all upper level trunk passages in both systems have been truncated by valley erosion which is evident from exploration and survey of those passages in both cave systems. The cave sections where connection is most likely are between the base level streams of both cave systems i.e. Red River in Whigpistle and at the downstream Logsdon River sump in the Mammoth Cave System. The gap between those two areas is almost two miles straight-line distance and under Woolsey Valley. Despite that distance the following evidence points to these areas as having the highest potential for connection.

Connection precedence

A review of the history of exploration and survey of the Mammoth Cave System connections (Kambesis 2007) reveals that most connections occur in the active base levels of two systems and that these areas cross under the deep erosional valleys that have truncated higher elevation passages. The Flint Ridge–Mammoth Cave connection occurred under those conditions and all other connections occurred in association with the active stream levels.

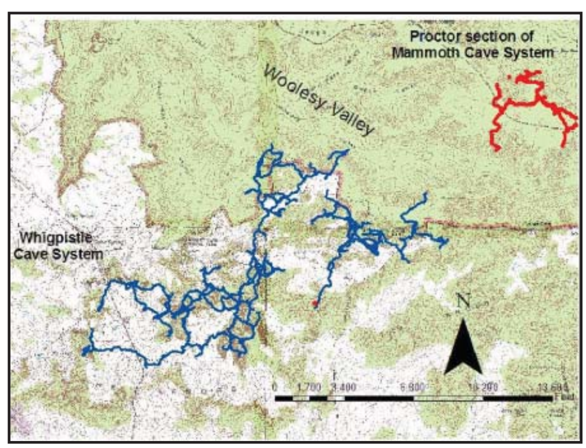

Figure 2: Topographic overlay showing location of Whigpistle Cave System and the Proctor section of the Mammoth Cave system.

Reassessment of the southwest sections of Proctor Cave

A considerable amount of time has been spent carefully remapping the Proctor section of the Mammoth Cave System in search for lower level routes that might bypass the downstream Logsdon River sump. Though plan view maps of the Proctor section give the impression of most favorable geography, the cave passages in that part of Proctor Cave are not deep enough to go under Woolsey Valley as evidence by cave and topographic elevation data.

Hydrology

The most compelling evidence for potential connection comes from the extensive amount of dye tracing that has been done in and around the Turnhole Basin which holds the Whigpistle Cave System and a good part (but not all) of the Mammoth Cave System drainage. A traced conducted by Quinlan (Courbon 1989) and reconfirmed by Jasper (1999) documented the hydrogeologic connection between the Hawkins-Logsdon River in the Mammoth Cave System and Red River in the Whigpistle System. Figure 3 illustrates the hydrological flow route as interpreted from both dye traces. Despite the amount of dye tracing that has been done in the area there are still hydrologic "mysteries" within this part of the groundwater basin. Groundwater flow from Mill Hole (located downstream of Whigpistle Cave System), has more stream discharge than the upstream rivers of Mammoth Cave. This groundwater flow, referred to as the Mill Hole River by Jasper (1999) has not yet been encountered by cave exploration efforts (though it is known to exist from dye tracing). Large cave passages formed by such a river should exist in the downstream portions of the Turnhole Spring Basin (Jasper 1999). The only significant cave passages ever found to date in the central portions of Turnhole are the 35 miles of the Whigpistle Cave System.

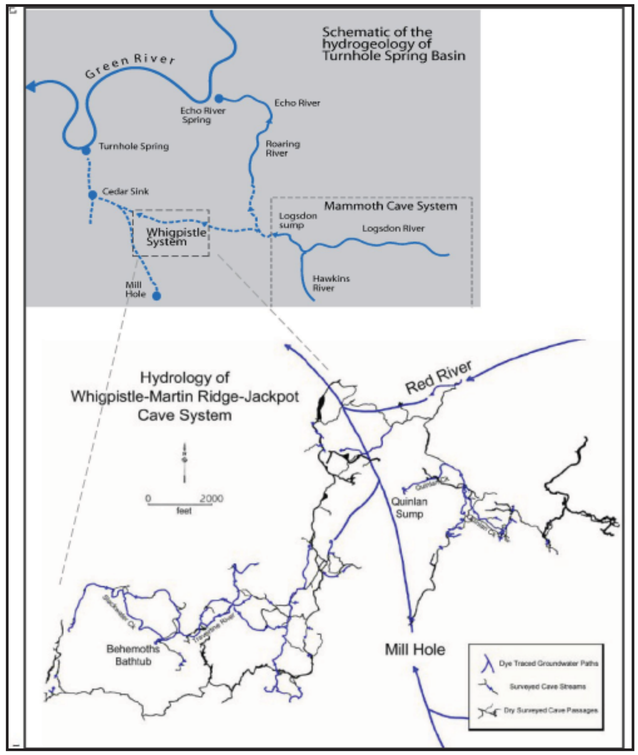

Figure 3: Schematic of the hydrology of Whigpistle Cave System with inset showing schematic of hydrology of Turnhole Spring Basin.

Connection Logistics

Because all of the underground rivers in the Mammoth Cave System that trend toward the Whigpistle Cave System become sumped (cave passages become water-filled), standard cave exploration techniques will not achieve the desired connection. However, technical cave diving can provide the means to make the survey connections necessary to link the two systems. In 2008, the author began working with a team of experienced cave divers toward achieving this goal. Discussions to consider logistics for working the downstream sumps of the Mammoth Cave System are in progress with the Resource Management office at Mammoth Cave National Park and several reconnaissance trips have already taken place in order to assess the conditions for cave diving in the sumps.

The Red River section of the Whigpistle Cave System is also in the process of being reassessed for potential efforts from that direction. The last trip to Red River occurred in the Fall of 1983 before the big storm that made that section of cave inaccessible from the Whigpistle entrance. The survey team documented a complex maze of stream passages some which sumped and others which were left as open leads. No one has been back to that area since. Plans are in progress to send survey teams to Red River from the Martin Ridge entrance of the Whigpistle System to continue working those leads.

Epilogue

Though the superlative length of the Mammoth Cave System and mileage potential for the Mammoth Cave area seem unbeatable on the world class scale, there is one other karst area that has the potential to surpass the Mammoth Cave area in terms of sheer passage density and possibly even cave system length. That area is located on the Yucatan Peninsula at the Caribbean coastline of the state of Quintana Roo, Mexico and is known as the Mayan Riviera. Like the Mammoth Cave area, tourism is the economic base, and caves play a significant roll as tourist attraction. The biggest difference in terms of caves between the two areas is that the Quintana Roo caves are predominantly underwater. Exploration of the cave systems of the Mayan Riviera began in the early eighties and to date over 1000 km of underwater cave passages have already been document. An additional 100 km of caves are located in the vadose zone i.e. no SCUBA or rebreather technology is required. In August of 2012, a dry connection between two underwater caves systems, Sistema Sac Actun and Sistema Dos Ojos, resulted in a cave system of 180 miles (303 km) in length and secured the number two position on the World's Longest Caves list (Heyer and Sprouse 2012). There are currently 223 known cave systems under the Mayan Riviera – the potential for more connections is imminent (QRSS 2012). This extra bit of competition on the world cave length scale is a "gentle" push for pursuing more connections to the Mammoth Cave System.

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In-Cave and Surface Geophysics to Detect a "Lost River" in the Upper Levels of the Mammoth Cave System, Kentucky

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Abstract
In early 1960, explorers accessed a significant underground river through a crawlspace beneath a ledge in Swinnerton Avenue southeast of the Duck-Under. However, later expeditions failed to find this crawlspace. Instead, the level of sediment in the passage is now generally at or above the rock ledge, leaving no openings to lower level passages other than the Duck-Under itself. Apparently recent organic material (leaves, twigs, etc.) observed in passages just below the Duck-Under may be related to open channel flow from storm events which could theoretically provide local sediment transport. Therefore we have used in-cave spontaneous potential (SP), ground penetrating radar (GPR), and acoustic profiling, as well as surface mise-a-la-masse resistivity profiling, in an attempt to locate the river itself rather than the missing crawlway. In-cave dye studies and additional geophysical profiling are needed to work out the detailed 3-D hydraulics of this region of the cave system.

Background and Purpose
At least two cave explorers recall accessing a significant underground river through a crawlway beneath a ledge in Swinnerton Avenue on the upper level of the Mammoth Cave system just southwest of the Duck-Under on January 2 and March 19, 1960 (see Figure 1). Recent expeditions to Swinnerton Avenue (in the 1980s and 2000s) failed to find this crawlway. Instead, the rock ledge in the area where the explorers recall the crawlway is at or only slightly above the level of sediment in the passage. Previous expeditions in 2007 and 2010 failed to find the crawlway, but did identify sediment transport features (ripple marks with gypsum fluff in the troughs, and gravelly rills; see Figure 2). However for sedimentation to have concealed the crawlway, it must have occurred between the 1960s and 1980s, and cosmogenic dating of sediments at the level of Swinnerton indicates that they have been underground for about 2.5 million years (Granger et al, 2001). In addition, according to records of the USGS gauging station BRKN2 just south of Mammoth Cave at Brownsville, KY, the largest flood since 1905 occurred on January 24, 1937 and raised the Green River 44.94 feet above normal pool (NOAA, 2013). This is far less than the 200 or more foot rise (Palmer 1981) necessary to backflood Swinnerton Avenue. However, the authors have observed recent organic material in passages just below Swinnerton in 2003, 2007, and 2010, as well as flowing water in a narrow (impassable) channel obliquely crossing Swinnerton north of the Duck-Under, suggesting open channel flow of infiltrating surface water. Such flow, particularly if it is intense during and/or after storm events could have moved sediments within the cave. Alternatively localized aeolian sediment transport within the upper levels of Mammoth may be indicated by a famous set of "dunes"

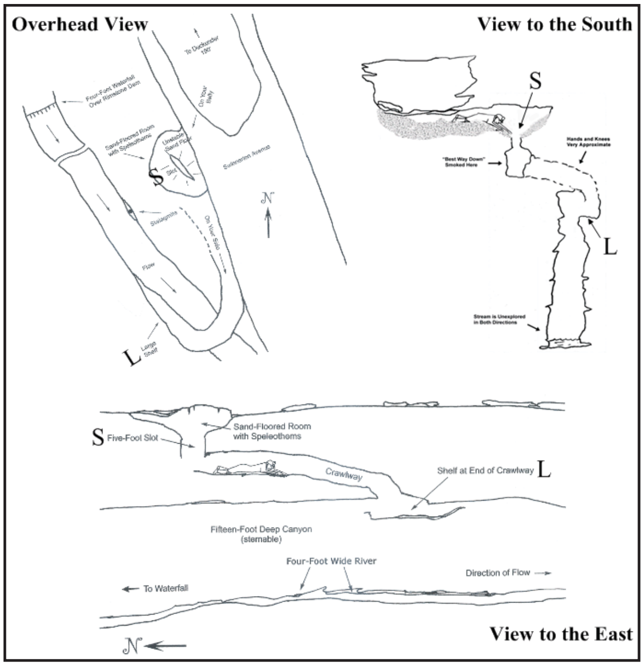

Figure 1: Eyewitness sketches of the crawlway to the "Lost River". For orientation, the slot is labeled S in each view, and the shelf or ledge is labeled L.

in Turner Avenue, and by the preferential occurrence of gypsum fluff in the troughs of ripple marks as observed in Swinnerton itself (Figure 2).

The purpose of this investigation was to determine whether there is evidence in Swinnerton of recent sediment transport that could explain the apparent disappearance of the entrance to the "Lost River". In addition, while preparing for this study, the authors became aware of the "Three Springs Conundrum" formulated by Meiman et al (2001) based on dye tracing that showed that the disappearing stream fed by Three Springs has not been found underground, and that shallow and deep flow pathways may go in different directions. The volume and direction of flow in the "Lost River" as recalled by early explorers even before formulation of the Conudrum is consistent with a likely explanation for the Conundrum – that is, the Lost River is in the right place and flowing the right direction to represent the swallowed Three Springs water. Thus, a second complementary purpose became collection of data that might indicate the path taken by water that emerges at Three Springs, and is quickly lost again into the Mammoth plumbing system.

2010 Spontaneous Potential Survey

In order to check for evidence of relatively recent water flow in Swinnerton Avenue, an expedition was undertaken in August 2010 to perform spontaneous potential (SP) measurements in Swinnerton Avenue southwestward from the Duck-Under. The SP method involves measuring the

Figure 2: Photos of aeolian phenomena from 2010; a) one of the apparent "dunes" in Turner Avenue, and b) gypsum fluff in the troughs of ripple marks in Swinnerton Avenue.

electrical potential field caused by naturally occurring DC electrical currents in the earth. Natural electrical currents occur nearly everywhere in the earth, and may be due to myriad phenomena, but in karst areas are generally dominated by the movement of subsurface water or the electrokinetic effect. This is a well-known (but little understood) phenomenon that arises wherever a pressure gradient causes fluid to flow through the capillaries of a permeable medium and evokes a charge separation in the bulk material. As a result, one can observe a decrease in the electrical potential in the direction of fluid flow, with the magnitude of the anomalous potential linearly related to the fluid flow velocity (Bechtel et al, 2007).

On the 2010 expedition, the crew used an Advanced Geosciences, Inc. Sting R-1 as a high impedance voltmeter (in SP-GRAD mode), and a pair of ceramic, non-polarizing electrodes to measure the SP gradient at ten-foot intervals along a roughly 1200 foot profile. The profile indicated a smooth gradient downwards towards a zone of negative values approximately 200 feet southwest of the Duck-Under – near the historical crawlway, with values rising smoothly beyond this to become positive again. The smooth gradient is consistent with water movement through the Swinnerton sediments towards the negative anomaly, and downward infiltration in the anomaly. However, the SP data do not reveal the age and timing (i.e. intermittent versus continuous) of this flow. On this expedition, it was observed that the May 5, 2010 Green River flood had enlarged the opening of a lengthy belly crawl in Pohl Avenue on the lowest level of the cave to allow mobilization to Swinnerton of bulkier equipment.

2011 Resistivity, GPR, and Acoustic Survey

In June of 2011 a second geophysical expedition was undertaken perform several measurements: (a) surface electrical resistivity profiling using the mise-à-la-masse technique in an attempt to determine the subsurface pathway of the water swallowed from the stream below Three Springs – that is the intention was to use electrons as a groundwater tracer that can be tracked from the ground surface; (b) in-cave ground penetrating radar (GPR) in an attempt to detect the Lost River crawlway beneath the rock ledge at the edge of Swinnerton, and (c) acoustic profiling in an attempt to listen for the flow of the Lost River where it reportedly crosses obliquely beneath Swinnerton.

For the resistivity survey, an attempt was made to make the Lost River behave as an electrical line charge (a variation on the mise-à-la-masse method; Telford et al, 1990). One current electrode was placed in the Three Springs stream, while the other was driven into the ground in the woods nearly a mile to the northeast. The R-1 was used in Resistance mode to drive a 400 Volt, 100 milliAmp current between these two, while measuring the voltage between two potential electrodes at a fixed separation of twenty feet. Each measurement was repeated in reversing polarity cycles until the cumulative error was less than three percent. Sequential measurements along three NW-SE profiles (roughly perpendicular to the presumed Lost River) covered distances of 800 to 1300 feet. The predicted electrical anomaly for this type of gradient measurement across a line charge is shown in Figure 3a. Note that the anomaly width is related to the depth of the line charge. Figure 3b shows the field data for the three profiles convolved with model anomaly profiles for line charge depths of 10, 20, 40, 80, 160, and 320 feet. The greatest correlation values are for a depth of 20 feet, followed by 10 and 40 feet, with low and decreasing values for 80, 160, and 320 feet. This indicates that the impressed current is probably flowing at a depth of about 20 feet – well above Swinnerton Avenue, and in fact probably within the epikarstic Haney

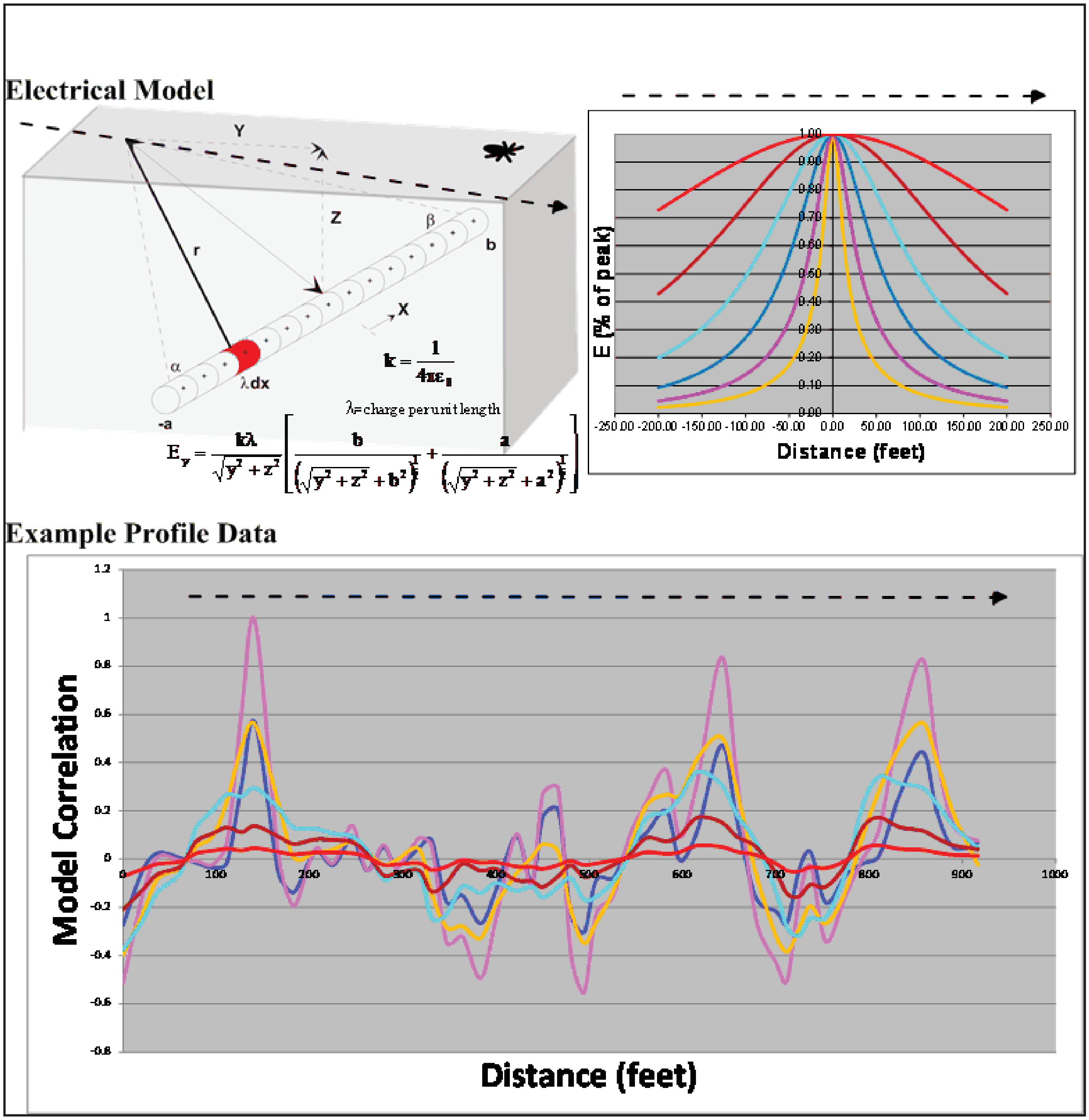

Figure 3: Mise-a-la-masse electrical surveying to detect subsurface flow related to Three Springs. Top; sketch and model data for different depth line charges (fluid flow conduits). Note how the anomaly width changes with flow depth. Bottom; data from one of the recorded profiles. The single profile of field data has been correlated with a sliding shape-matching filter to estimate the depth of current flow. Depths are gold-10, magenta-20, blue-40, cyan-80, brown-160, and red-320 (feet). Peak correlations for the magenta profile indicate dominant electrical flow at approximately 20 feet below ground. Dashed black arrows show the orientation of the profile relative to presumed line charges.

Limestone above the Big Clifty Sandstone that forms the caprock for the Mammoth Cave System. Thus, the electrical survey appears to be primarily tracking the water flowing towards Three Springs. There may be some signal from electrons flowing in the swallowed water downstream of the springs (which was the intended target), but the signal from the much shallower flow in the epikarst dominates. This highlights an important difference between using chemical or microsphere tracers (Benischke et al, 2007) versus electrons as groundwater tracers; electrons can flow upstream!

The in-cave GPR scanning was performed along the west ledge of Swinnerton using a GSSI SIR-2000 controller and a 400 MHz transducer. A prove-out scan across the Duck-Under produced a distinct reflection pattern (Figure 4). Since the Duck-Under is an air-filled passage, and the Lost River Crawlway may be partially sediment filled, a reflection set as remarkable as that in Figure 4a was not expected. Along the 1200 feet of GPR profile, numerous other reflections were detected (Figure 4b and 4c), but all of them were associated with recognizable (not hidden) features, and were too small to represent the lost crawlway.

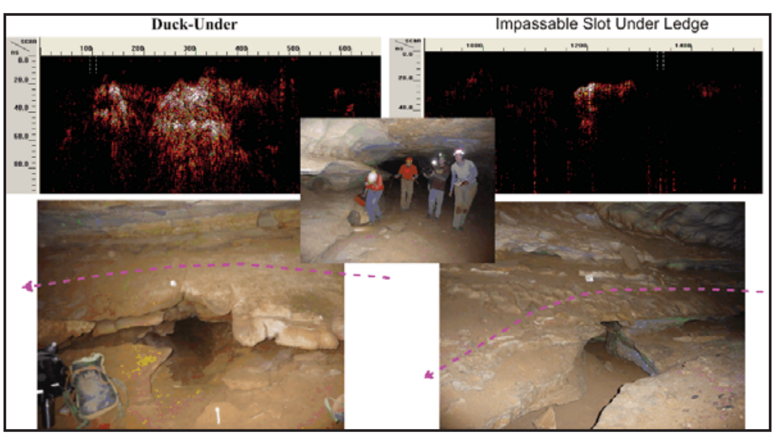

Figure 4: Example GPR profiles and their locations (dashed lines). Inset shows scanning of the ledge in progress.

Acoustic monitoring of the floor of Swinnerton was performed at five foot intervals using a Flow Metrix DLD detector. Relative noise levels were uniformly low along the survey area extending southwestward from the Duck-Under, but rose steadily eastward from the Duck-Under towards the visible stream that obliquely crosses Swinnerton. No flow sounds from beneath the floor of Swinnerton in the area of the suspected Lost River were detected.

While the in-cave geophysical surveys did not produce data to reveal the location and fate of the lost crawlway, the action of collecting the data forced a very thorough and careful inspection of the west ledge of Swinnerton. This inspection revealed four tin cans with flaking paper labels hidden in a crevice at floor level (Figure 5). The labels were sufficiently intact to recognize the cans as Banquet canned chicken and Diet Delight fruit cocktail. Contact with vintage advertising and food label collectors revealed that the Banquet cans date from no later than c. 1964, and the particular Diet Delight logo was used from c. 1951 to 1962. Since the labels are still partially intact, and light and fragile label flakes still lie in the bottom of the crevice (Figure 5), this garbological dating (Rathje and Murphy, 2001) indicates that there cannot have been significant sediment movement in this area of Swinnerton since c. 1964. Thus, any large scale sediment transport to conceal the entrance would need to have taken place between March 19, 1960 and sometime around 1964. Note that the persistence of the label flakes in the protected crevice does not preclude the aeolian (?) movement of light gypsum fluff, but transport of large enough volumes of sediment to bury a crawlway is not likely after c. 1964.

Conclusions

The results of this study indicate the following:

- Swinnerton Avenue lies at a level far above the highest historic backflooding levels.
- However, there is recent evidence of open channel flow of infiltrating water at the level of Swinnerton.
- The occurrence of gypsum fluff in the troughs of ripple marks in Swinnerton suggests aeolian movement of these light particles.
- Measured spontaneous potentials indicate that there has been movement of water within the sediments of Swinnerton Avenue, but the age of this flow cannot be determined.
- Electrical illumination of the water draining Three Springs (by the mise-à -la-masse resistivity method) revealed the flow paths of water draining towards the springs above the Big Clifty sandstone caprock. Swallowed water flowing in the Mammoth plumbing system (perhaps the Lost River?) was almost certainly illuminated as well, but the epikarstic flow close to the ground surface measurement locations dominates the recorded signal.
- GPR scanning of the west ledge in Swinnerton easily detected the known Duck-Under, and numerous smaller (impassable) side openings, but nothing large enough to represent a hidden crawlway.
- Acoustic monitoring led to a visible stream crossing Swinnerton northeast of the Duck-Under, but did not detect any distinct flow sounds from beneath the floor west of the Duck-Under.
- Discovery of food tins, dateable by their distinctive labels to the 1950s or early 1960s, and the persistence of label flakes on the floor of Swinnerton precludes large scale sediment transport after c. 1964.

Figure 5: Cans left by early explorers found in a crevice along Swinnerton Avenue. The date ranges of the flaking but recognizable labels indicate that they are undisturbed since c. 1964.

Eyewitness accounts of the Lost River are now over fifty years old, but were transcribed at the time in sufficient detail to strongly suggest its existence. In addition, the documented hydrogeology of the Three Springs-Swinnerton (three-dimensional) region nearly requires its existence. Further work to find the presumed river and explain the Three Springs Conundrum could include:

- Dye injection at Three Springs with monitoring at in-cave locations. This would identify connections to known flows, but not detection of the lost river.
- Another Mise-à-la-masse illumination of the Three Spring plumbing, but with potential measurements carried out in the cave – presumably closer to the plumbing system flow from the springs than to the epikarstic flow feeding the springs. This would

require independent decoupled current transmitter and voltage receiver since one will be at the surface and the other in the cave.

- In-cave gravity profiling using a compact meter (e.g. LaCoste & Romberg Model D Aliod) to detect potential passages beneath Swinnerton. Although gravity readings are omnidirectional (i.e. not discriminating between mass anomalies above or below the meter), since Swinnerton lies on the uppermost level of the Mammoth System, apparent gravity lows should be more likely to represent cavities beneath the floor than mass excesses overhead (and mass excesses are not expected geologically in this setting).

Finally, the evidence of aeolian sediment transport suggests that long-term monitoring of air movement in the cave (to detect possible short duration-high intensity events) using battery-powered, data logging anemometers might yield interesting data.

Acknowledgements

Thanks to Rick Toomey for facilitating cave access, and Chris Groves, Art Palmer, and Stan Sides for valuable advice.

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Sump Diving "River Caves"

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Abstract

Note: "Sump" is a term used in caving to describe a passage in a cave that is submerged under water.

Sump diving, and "lure of the sump" originated in the UK in the early 1920's, as did the use of "rebreather's, and the "self-contained underwater breathing apparatus", S.C.U.B.A. The techniques developed by cavers, and "sump divers" in Europe, and then used in British cave systems like Wookey Hole set a cave diving precedence; the development of a unique style, and system for diving caves. These diving practices and techniques influenced the exploration of resurgences, springs, siphons, and river caves throughout the world. This long history of bravery, and the unparalleled determination of cave divers continues today, and will certainly continue to shape the future of exploration as we know it.

The exploration of Roppel, Mammoth, Whigpistle, and other surrounding caves in Kentucky's Mammoth Cave area is ongoing, and from 1984 through 1999, sump diving Roppel attracted names like, Ron Simmons, Roberta Swicegood, John Schweyen, Tim Payne and Wes Skiles. Ron Simmons, Roberta Swicegood and Wes Skiles have since perished in diving related incidents. Let us honor and remember the investments they made, along with the other divers preceding them. Eight years later, in 2007, Mark Wenner, Brian Williams, Matt Vinzant (sump diver team #1), followed by Jill Heinerth and Jerry Murphy, (sump dive team #2), joined the small league of sump divers to dive beyond the upstream sump of the Logsdon River. Once beyond the waters' barrier, they broke into going cave passage, and 5 years later have yet to return to those leads to take them on. The finale of Wenner's Power Point presentation will feature photos and dialogue from that 2007 exploration of Swicegood Ave.

Figure 1: Nov. 19th, 2011, Mark Wenner exiting Ginnie Springs "Devils Ear", decompression on 100% O_2 after a scooter dive, photo by Tom Johnson.

For the past 7 years, Wenner has joined various teams, focused on the exploration of dry cave passage in Roppel, attempting to break into South Toohey Ridge. Wenner joined the Cave Research Foundation, primarily as a diver, which proved to be a short coming, and working on dry caving projects was a quick study method of coming to speed with that knowledge. The need for comprehensive dry caving experience was recognized in his 2007 efforts to push Logsdon River. The 2007 dive team recognized the high level of dry caving skills used by Mammoth

Figure 2: June 26, 2006, Mark Wenner knitting up to dive the upstream sump of Snail Shell Cave, photo by Brian Wiilliams.

cavers, in support of the diving efforts in Logsdon River. This particular dive team was also pushing other river caves in TAG (Tennessee, Alabama, and Georgia), the Yucatan, and Dominican Republic, etc. Over time, and in developing better dry caving skills, single rope techniques, and more experience with survey and mapping, it provided a solid foundation for working in extremes.

In 2012, Rick Olson, Rick Toomey, representing the National Park Service, and Pat Kambesis representing Cave Research Foundation contacted the sump diver team of Wenner, Williams and Vinzant. Throughout this past year, multiple reconnaissance trips have been staged to gather and provide the information necessary to push leads in the Mammoth Cave system. The starting point for this recon work, was the relatively short trip down the Doyle entrance to the downstream section and sump of the Logsdon River. Later that spring, with similar efforts came the discovery of a blue hole, or deep section in the rivers bottom, in the upstream sump area of Roaring River! This river, in 1988 had been the focus of a Kentucky Cave Shrimp Census program, and cave divers then had run dive line into various dive leads on the east and west walls of the river passage. No diving in the Mammoth Cave system had been approved since that study, and last year, July of 2012, that changed. With copious amounts of help from Rick Olson, Rick Toomey, and Pat Kambesis, Mark Wenner submitted a "dive objective" plan for taking on the leads they had found earlier in the year, on previous kayak trips up the river. They have since staged two explorations, which were both aborted due to Hurricane Ike on Labor Day, and again on October 6, 2012. Cave diving river caves is completely dependent on near perfect weather conditions.

Our goal, as a sump diving team, is to represent the Cave Research Foundation, and the National Park Service on cave projects, exploring those possibilities to their extent. Our greatest strength is, the previous examples of our work in past CRF explorations, the relationships we have

Figure 3: Oct 7, 2011, Mark Wenner and sump mentor Forrest Wilson, after running 1000' of fresh dive line into a virgin cave in AL called "Odells" during TAG Cave In. Photo by DeWayne Hyatt

built over the years, the experience and ability to collect data, and going beyond where it is possible to go, without extensive experience and qualifications.

The following things will be discussed during this presentation:

- What differentiates a sump diver from a cave diver?
- Why do we do it, and what have we seen?
- What equipment is used to dive sumps, and basic terminologies.
- The marriage of the caver and sump diver.
- The equipment and various techniques of diving.
- Diving with tanks, versus diving with rebreathers.

Photos included from other "River Caves" Explored:

- Snail Shell Cave
- Blue Hole of Elliston
- Windy River Cave
- Jackson Cave – Cedars of Lebanon
- Espey Cave
- Hayes Spring in Eastern KY
- Guy James
- Blue Springs Cave
- The Dominican Republic
- The Yucatan
- Mammoth and Roppel Caves

Figure 4: March 7. 2008, Mark Wenner and Brian Williams doing recon on water levels and historic dive line conditions, Logsdon River upstream sump, while a snow and ice storm raged on the surface, making exit from Wellar Entrance and back to CRF Hamilton Valley close to impossible. Photo by Matt Vinzant

Who Am I?

Who am I, to dare take on something, so much grander than I.

So many endless years of power we know little about.

How can water cut stone?, and lead us to our question of what is beyond the beyond.

So strong is our desire to know, we risk ourselves; risk everything to know, and question it more, day after day, "who am I".

The cave and its darkness know, the silence, the mystery, the path leading us there.

The calling is there for us, without a sound, unless you're quiet long enough to hear.

Paleontology and Paleoecology of Interglacial Guano Deposits in Mammoth Cave, KY

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[1] Illinois State Museum

Abstract

Mammoth Cave guano deposits contain a rich record of troglofauna spanning the last 125,000 years. In particular, chiropteran remains from Chief City provide insight into ecosystem dynamics of the cave area during the last interglacial. This paper presents results of paleontological excavations undertaken in 2008.

Sub-fossil remains (N=1134) in Chief City guano deposits are dominated by chiropteran taxa. Although all identified taxa are extant, the combination of *Myotis leibii* and *Tadarida brasiliensis* is an association without modern analogue. Stable isotope analyses of guano indicate a C3 prey signature characteristic of forested habitat. This was unexpected given the prevalence of *T. brasiliensis*, a species that is typically associated with open environments.

Ecomorphological consideration of wing shape trends in these assemblages indicate that interglacial faunas are dominated by fast-flying, open-space taxa (*T. brasiliensis*) while late Holocene and Historic assemblages contain more taxa that utilized closed forest or forest gaps.

Using S Isotopes to Identify the Source of Gypsum in Mammoth Cave

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Abstract

Many of the dry passages of the cave are lined with gypsum (CaSO4•2H2O) crystals, an evaporite mineral. However, the source of the sulfur in these gypsum deposits is poorly constrained with possible sources including pyrite, sedimentary gypsum/anhydrite, and carbonate associated sulfate ("CAS", SO42- substituted for CO_3^{2-} in the calcite crystal lattice). The two most abundant forms of sulfur in the bedrock above and around Mammoth Cave are pyrite (FeS_s) and CAS. These phases commonly have very different isotopic signatures ($\delta^{34}S$)* and the $\delta^{34}S$ values of these phases can be compared to the $\delta^{34}S$ of the gypsum to aid in identifying the source of the sulfur. Isolation of sulfur from pyrite and CAS is currently ongoing. Results from 110 gypsum crystals, 4 rocks in strata from within the caves, and 15 rocks from strata overlying the caves reveal some distinct patterns. 1) Gypsum crystals show relatively small scatter (~5‰) for samples from a single location (e.g. a 30 m^2 room). 2) A significant correlation between $\delta^{34}S_{gypsum}$ and elevation suggests a variable $\delta^{34}S_{source}$ over vertical distances of a few meters. 3) Microsampling of sulfur along the growth axes of single gypsum crystals shows a constant $\delta^{34}S$ values suggesting no change in $\delta^{34}S$ of the S source during its growth. Because the growth period of these crystals may be on the order of thousands of years, these results suggest a constant sulfate for long intervals. The relationship to $\delta^{34}S$ of samples in a given room and elevation suggests that the source of gypsum sulfur is local, arising from lateral, rather than vertical, fluid flow, an important insight into the transport pathways of water in a karstic system. Sampling of pyrite and CAS is currently ongoing.

*$\delta^{34}S = [(^{34}S/^{32}S_{sample})/(^{34}S/^{32}S_{standard})-1]\bullet 1{,}000‰$ where ^{34}S and ^{32}S are the molar ratios of each S isotope given in "per mil" (‰), equivalent to parts per thousand.

Particulate Inorganic Carbon Flux in Karst and its Significance to Karst Development and the Carbon Cycle.

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Abstract

Chemical removal of carbonate is generally assumed to dominate the inorganic carbon cycle in karst, but mechanical removal of carbonate during storm events may be significant. To determine the significance, particulate inorganic carbon (PIC) flux in bed load and suspended load is being quantified and compared to dissolved inorganic carbon flux in three karst systems: Mammoth Cave, KY; Blowing Cave, KY; and Tumbling Creek Cave, MO

Analysis of Kyrock for Leaching of Impurities in Synthetic Rainwater

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Abstract

Kyrock is a coarse grained sandstone with a complex mixture of organic and inorganic compounds. Mining of Kyrock was for use in road construction and roofing. Kyrock samples were analyzed using Scanning Electron Microscopy to obtain Elemental analysis. High levels of carbon indicate the presence of organic compounds. Analysis of an acid digestion of the samples using Inductively Coupled Plasma spectroscopy inorganic compounds such as titanium oxide, vanadium oxide along with traces of a arsenic. Elemental analysis of samples shows a six percent of carbon, and 5-6 percent sulfur with no notable traces of Nitrogen. Pyrolysis of the samples was done using Gas Chromatography Mass Spectroscopy with a gradual increase in temperature to 160o C to obtain a series of inorganic-organic compounds. Synthetic Rainwater was prepared to examine the leaching of compounds and the leachate was analyzed using Liquid Chromatography Mass Spectroscopy and Gas Chromatography Mass Spectroscopy.

Geophysical Logging of a Park Well, Mammoth Cave National Park, Kentucky

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Abstract

Geophysical logs are used to measure various physical properties of the underlying rock formations or the fluids contained in the rocks. Probes that measure different properties are lowered into a well or borehole and the measured data are displayed by depth. The properties displayed in the geophysical log can then be correlated to known geologic formations, changes in rock type, or changes in rock or fluid properties. The two types of logs run at Mammoth Cave were natural gamma and caliper. Gamma logs record the amount of natural gamma radiation emitted by the rocks surrounding the borehole. Clay and shale-bearing rocks commonly emit relatively higher natural gamma radiation. Caliper logs record borehole diameter. Changes in borehole diameter are related to well construction, such as casing or drilling-bit size, and to fractures or openings encountered along the borehole wall.

Geophysical logs were run at the Mammoth Cave National Park to evaluate the use of geophysical logging at the park and to evaluate the condition of the wells for use in other investigations. Four wells were evaluated for geophysical logging; logs were collected in two wells and two wells could not be logged due to access or obstructions in the borehole. Geophysical logs were run in a well near Cedar Sink and in the USGS observation well near the Mt. McKinley Pumphouse. Natural gamma logs were run in both wells and a caliper log was also run in the deep observation well. The observation well is at an elevation of about 865 feet and was logged over a total depth of 492 feet, to an elevation of 373 feet. The geologic formations encountered in the observation well include the Big Clifty Sandstone Member, the Girkin Formation, the Ste. Genevieve Limestone, and into the St. Louis Formation. The Cedar Sink well, at an elevation of about 575 feet, was logged over a total depth of 140 feet to an elevation of 435 feet. The Cedar Sink well begins in the Girkin Formation at land surface and may terminate near the contact with the underlying Ste. Genevieve Limestone.

Geophysical logs can be used to correlate specific formations or features across the Mammoth Park area. Results from the logging and correlation can be used to improve the understanding of the regional geology, geologic structure, and the relation of those features to the unique groundwater hydrology of the karst and cave features of the Mammoth Cave National Park.

Karst Hydrogeology of the Haney Limestone, South Central Kentucky

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Abstract

South-central Kentucky has one of the world's most intensively studied karst areas, with most work focusing on the Mammoth Cave System and the related aquifers within the Mississippian St. Louis, Ste. Genevieve and Girkin Limestones. Within much of the Mammoth Cave Plateau, these limestones are overlain by the Big Clifty Sandstone and other formations that form a protective caprock within the area's major ridges. Above the Big Clifty, in turn, is the Mississippian Haney Limestone, typically about 12 m thick, which forms a locally important but much less well studied carbonate aquifer. This research provides the most comprehensive hydrogeologic synthesis to date of the karst hydrogeology of the Haney Limestone within south-central Kentucky, in the present study including Warren, Hart and Edmonson Counties.

Analysis of landforms, surface and subsurface drainage, and karst features shows that there is a range of karstification intensities across formation outcrop areas. A total of ninety-three caves and forty-nine springs were identified within the study area. Known caves are not evenly distributed, with relatively high densities within Mammoth Cave National Park, where there is long history of systematic exploration and documentation of caves by the Cave Research Foundation, and near Bowling Green where there is a relatively high number of cavers. This suggests that more caves are likely to be found in areas that have not been as thoroughly investigated.

Recharge forming Haney Caves is largely allogenic where the formation's upper contact with Hardinsburg Sandstone is exposed and concentrates flow, at sinkholes that breach the Hardinsburg or within downcutting stream valleys. Other recharge lands directly onto the Haney karst surface on localized sinkhole plains, or leaks as diffuse flow through the overlying Hardinsburg. Conduit morphology and development have been strongly influenced by joints in the bedrock and passage characteristics suggest little phreatic influence on conduit enlargement. Cave entrances are frequently perennial spring resurgences and the high proportion of active streams suggests that the caves are a function of the current landscape, acting as drains for localized recharge areas. This suggests that caves in the Haney Limestone were not directly influenced by the incision of the Green River in a way similar to Mammoth Cave, but that cave development is a much more recent and local process.

The most significant cave in the study area is Cub Run Cave in Hart County, with more than two kilometers of mapped passages, most of which is a large trunk along the main stream. The cave occupies the full thickness of the Haney, with both the overlying Hardinsburg visible in the ceiling at places, as well as a shale layer at the Haney/Big Clfty contact below. An upper section of the cave's northwest extent continues upward through the Hardinsburg and into the overlying Glen Dean Limestone. Although groundwater tracing would be necessary to carefully constrain the cave's recharge area, based on apparently topographic divides on the Hardinsburg it is about 1.7 km2. This apparently small catchment suggest that the large passages (up to 15 meters in diameter) may result more from a long period of dissolution that a large contributing area.

Mysteries of the Underground River

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Abstract
Have you ever heard of a river that that flows backwards? Mammoth Cave, the longest cave system in the world, has an underground river exhibiting reverse flow patterns since at least the 1960's and most likely earlier. Beginning in 2009, 7th graders from T.K. Stone Middle School in Elizabethtown, Kentucky have been teaming with WKU researchers to study and conduct research about this phenomenon.

Introduction
Normally, the underground River Styx discharges into the nearby Green River at the River Styx Spring. When this underground river reverse flows, water from the Green River floods the River Styx.

When first discovered, scientists were using methods to test the flow which produced limited information. Initially, researchers tested chemical characteristics to see if chloride content could be used as a signal of reverse flow patterns.

Eventually, scientists found that water temperature was the best indicator of reverse flow. When in reverse flow, the temperature of River Styx goes outside its normal temperature boundaries due to the influx of water from the Green River.

Scientists have, in fact, studied the temperatures of two underground rivers in Mammoth Cave to find out more about the reverse flow. Adjacent to the River Styx, the Echo River is a fairly consistent 13.5 to 14.5 degrees Celsius, making it a natural control site for monitoring water temperatures during periods of normal and reverse flow in the River Styx.

Student Research
The T.K. Stone student research team, led by researchers Rick Toomey and Shannon Trimboli and teachers Susan Ryan and Kim Weber, installed HOBO® data loggers in the Green River, the River Styx and the Echo River in October of 2009. Using this updated technology, the data loggers record temperatures every two hours in all three locations.

Since 2009, each spring and fall, current 7the graders from T.K. Stone travel to Mammoth Cave and hike nearly two miles to transfer information from the data loggers to a HOBO® shuttle which stores the temperature data until downloaded.

Think Outside the Cave
Students continue their work back at the school throughout the winter using Microsoft Excel to condense the large amount of data into graphs and charts for further analysis.

The partnership between the school, WKU, and the National Park Service has allowed the students to experience real-life science investigations. Using applied math and science, students analyze their findings and converse with WKU partners regarding their ideas for future investigations in relation to this underground mystery.

An Alternative to the Advection Dispersion Model for Interpreting Dye Tracing Studies in Fractured-Rock and Karst Aquifers

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Acknowledgment - Tom D. Byl[1,3]

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[2] Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park, Western Kentucky University
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Abstract

Due to the complexity of groundwater flow in fractured-rock and karst aquifers, solute transport models for these aquifers are typically stochastic models based on tracer transport studies. Water and tracers do not flow at one single advective velocity but experience a wide range of velocities, from rapid flow in conduits to near stagnant conditions in adjacent voids. This variance of velocities is referred to as dispersion and is traditionally described mathematically by the advection-dispersion equation (ADE). Analytical solutions to the ADE are available and are referred to as advection-dispersion models (ADM).The ADM is fitted to the tracer data by varying the parameters until a best-fit is achieved between the experimental residence time distribution (RTD) and the model RTD. The major shortcomings of this approach are due to the symmetry of the ADM and its associated prediction of finite concentrations at zero time and its inability to reflect the long upper tail typical in experimental RTD data. This paper presents an alternative conceptual approach to the ADM for modeling solute transport in fractured-rock and karst aquifers. In this approach the variance in flow velocities and flow path lengths are addressed directly by treating them as random, gamma distributed variables and deriving the RTD from a transformation of random variables based on the ratio of length to velocity and representing the RTD as a conditional probability distribution of time. The resulting four parameter (Gamma-RTD) model is relatively easily parameterized since the flow path length is tightly distributed about the known straight line distance between the injection point and the effluent. The model is demonstrated and contrasted to the ADM below by applying it to tracer data from a quantitative tracer study at Mammoth Cave National Park. The results indicate that the Gamma-RTD is superior to the ADM in modeling the shape as well as the area of the experimental RTD.

Introduction

A descriptive, probabilistic mathematical model was developed to model karst aquifers which is based on the gamma distribution. The gamma distribution is a function of random variables that are exponentially distributed and is frequently used as a probability model for waiting times studies. In hydrological karst studies, the gamma distribution can create an appropriate RTD as it is a two parameter model and allows for flexibility to account for nonlinearities. It is unclear which physical interpretation can be ascribed to the gamma distributions' two parameters (α, β). To address this, a gamma distribution for the residence time was derived by assuming that the velocity and travel distance of the karst system were gamma distributed random variables.

This gamma distribution RTD model was tested on a natural karst system at Mammoth Cave National Park. That model was compared to the results of the traditional Advection Dispersion Equation

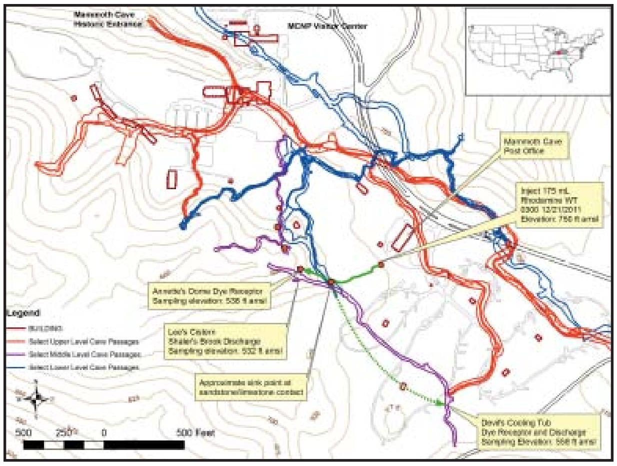

Figure 1: Topographical map of cave features with surface overlay. Injection point and tracer flow path indicated in green. Different levels in the cave are indicated by different colors.

(ADE) RTD model (see Painter, et. al. for a thorough discussion of the ADE RTD model). A quantitative rhodamine dye study was run to determine the travel time from the outlet of the Post Office filter which is indicated in Figure 2. The test was set up on the afternoon of December 20, 2011, because it was supposed to rain, but the rain came much later (around 3 A.M. on December 21). A tipping delivery system was triggered by the rain event and released both salt & rhodamine dye. (This set up is described more in the Materials and Methods section.)

At the outlet of the stormwater treatment system, which services the post office parking lot, a stream forms which empties into the cave approximately 875 feet downstream. Inside the cave as indicated in the Figure 2, the stream has been shown to empty into an area known as Annette's Dome and portions also enter into another area called the Devils Cooling Tub both located approximately 200 feet beneath the surface. Annette's Dome creates another feature known as Shaler's Brook, located approximately 60 feet beneath the ceiling. Shaler's Brook receives direct discharge from Annette's Dome, therefore it is used as an endpoint in the dye study along with Devil's Cooling Tub. These subsurface areas were selected because previous tracer data indicated relatively rapid rates of surface recharge at Devils Cooling Tub and Shaler's Brook. At Devils Cooling Tub discharge rates ranged from 0.5 L/min to 51.95 L/min. Discharge measurements for Shaler's Brook were taken at the formation known as Lee's Cistern, which receives direct discharge from Shaler's Brook approximately 50 yards downstream. Lee's Cistern discharge measurements ranged from 6.57 L/min to 176 L/min.

Materials and Methods

Discharge measurements were collected at Lee's Cistern and Devil's Cooling Tub at various dates preceding the quantitative dye tracer study. These discharge measurements were used to determine the amount of dye needed to avoid poor results from excessive dilution, but also remain within a safe range to preserve the karst ecosystem. At Lee's Cistern, discharge was measured using a plastic

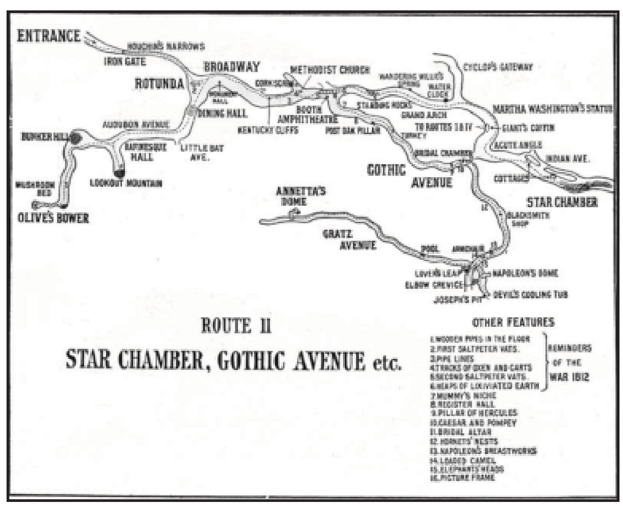

Figure 2: 1908 Tour Map showing the 200 feet level of the cave showing cave features by their colloquial names, which are used to this day. Annette's Dome and Devils Cooling Tub were referred to in this study (Hovey, 1909).

tarp to concentrate the stream, and then recording the amount of time needed to fill a container of known volume. This was done in triplicate. At Devil's Cooling Tub, a similar procedure was followed to measure discharge.

The quantitative dye study was conducted on December 20, 2011, beginning on the surface at the outlet of a stormwater filter, which services parking lots adjacent to the post office on the park grounds. Inside the cave, fluorometers with rhodamine sensors and first flush samplers were placed in two areas of the cave where they measured the amount of time taken by the dye to move through the karst system. The locations within the cave, Shaler's Brook and The Devil's Cooling Tub, were selected because they were suspected to interact with the surface relatively rapidly and provide surface recharge for two major karst springs in the formation, Echo River and River Styx. Dye selected for the study was Rhodamine WT-20. Concurrently, a salt tracer study was also conducted to gain additional hydrologic data. The tracers were set up on a release mechanism, see Figure 3 for the setup. The release mechanism consisted of a Styrofoam tray with approximately ¼ lb of table salt (114 g NaCl) laying flat on the tray and 175 mL of Rhodamine WT-20 in a plastic bottle standing upright on the tray. This mechanism was placed in the outlet of the storm filter system. Below, we placed a first flush sampler (white plastic container with the red lid) and a YSI datasonde (to measure the salt concentration) set to read every 5 minutes. [Additional first flush samplers and YSI datasondes with rhodamine sensors set to read at 20 minute intervals were placed in the cave. See Figure 4 to see the location of the datasondes and the first flush sampler in Shaler's Brook.] As the storm waters exited the filter, they reached a high enough velocity to flush the tray out and spill it. The tray was elevated approximately 0.5 inches in the discharge pipe to keep it from dumping on the very first trickle; rather, it needed enough flow to lift it and destabilize it. At 3:00 A.M. on December 21, 2011, both tracers were released.

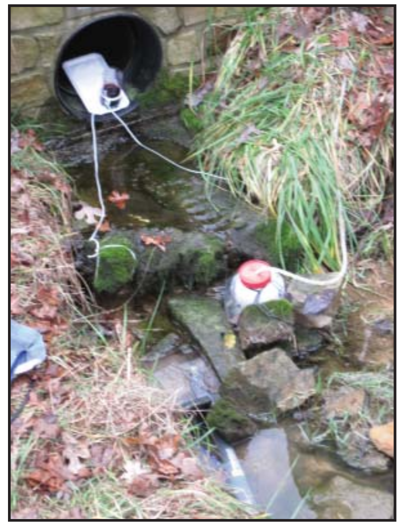

Figure 3: Photograph showing the dye and salt release mechanism. Also shown in the picture are the first flush sampler and the YSI datasonde.

Figure 4: Photograph showing the pool at the bottom of Annette's Dome and the beginning of Shaler's Brook. Also pictured is the YSI datasonde with the first flush sampler.

Results

The results of the Rhodamine WT-20 quantitative dye study at Mammoth Cave are shown in the following graphs and tables. We have only analyzed the results from Shaler's Brook thus far, we will describe the other results in a future journal article.

The results from numerical integration of the concentration versus time data for the tracer study conducted are shown in Table 1. Table 2 displays the numerical integration of the normalized gamma RTD versus the normalized time. Figure 5 shows the tracer breakthrough curve. The results of the dye study were then used to develop the residence time distribution (RTD) function. The RTD function (E(t)) for contaminant molecules in a single karst conduit or a complex system of conduits is a probability density function (PDF) which can be interpreted to define the probability that contaminant molecules present at the influent at time equals zero will arrive at the effluent after a particular amount of time. The RTD is depicted as a plot of E(t) versus time as time goes from zero to infinity.

E(t) was determined by injecting a pulse of a conservative tracer (Rhodamine WT-20) into the cave system by the mechanism shown in Figure 3 at time (t) = 0 and then measuring the tracer concentration in the effluent as a function of time.

The experimental normalized (dimensionless) RTD from the numerical integration of the tracer data is shown along with the normalized Advection Dispersion Equation (ADE) RTD and the normalized Gamma distribution RTD model in Figure 6.

Discussion and Conclusions

Based on the graphical evidence presented in Figure 6, the Gamma distribution RTD better resembles the experimental RTD for the Shaler's Brook area. Also, the area beneath the curve is a better fit for the Gamma model RTD rather than the ADE RTD model. In addition, it is possible to calculate the mean velocity and the mean distance traveled from the Gamma distribution RTD which is not possible with the ADE RTD. For those reasons, we conclude that the descriptive, probabilistic, Gamma RTD model better mathematical models this particular karst site at Mammoth Cave, Kentucky.

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The History and Conservation of Saltpeter Works in Mammoth Cave, Kentucky

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Abstract

Remains of the saltpeter mining operation in Mammoth Cave are a significant feature of several cave tours and figure prominently in the history of cave use. We undertook a comprehensive review of existing historical descriptions and recent archaeological investigations to construct the most reasonable account of how the saltpeter operation worked and assess its current conditions. At least three types of saltpeter vats were constructed in the cave reflecting an increase in the size of the operation and efficiency of processing sediments over time. Remains of three pump towers are also found in the cave in various states of preservation. The water pipe system was mostly dismantled, but archaeological evidence indicates its most probable route through the cave. We recommend more thorough documentation of existing remains, conservation efforts to preserve existing remains, better interpretative signage, and possibly repair or replication of damaged or missing components to further enhance public interpretation.

Introduction

The niter mining and saltpeter conversion process at Mammoth Cave was a sophisticated industrial engineering operation in its day during the War of 1812. While portions of the mining works are preserved in the cave's stable environment, significant portions have been dismantled, buried, or destroyed and on-going processes threaten to eventually destroy the remaining wooden works. On a visit to Mammoth Cave in the mid-1830s, Robert Bird (1837, 1838) describes his guide building a fire in the Rotunda using the wooden saltpeter remains to light the cave:

> *". . . he falls to work on certain old wooden ruins, to you yet invisible, and builds a brace or two of fires; by the aid of which you begin to have a better conception of the scene around you. You are in the Vestibule, or ante-chamber, . . ." (Bird 1838: 86).*

As much as we might cringe at this thought today, in 1837, with the War of 1812 only 22 years in the past, historical preservation was not a concern. Through the years, as Mammoth Cave has been developed to accommodate increasing numbers of visitors, preservation of the saltpeter works has been only an occasional concern. Even as late as the 1990s, it was reported that a collection of wooden pipes and other wooden debris was collected in the Rotunda in preparation to be carried from the cave for disposal as part of a cave clean-up project. Fortunately, this was discovered in time and halted. Less conspicuous, but still a serious threat, is the slow but steady disintegration of wooden remains by fungal action, condensation, and other natural cave processes, such as roof fall that significantly damaged saltpeter remains in the Rotunda in the early 1990s.

The University of Kentucky Museum of Anthropology with technical assistance from Pennsylvania State University and Texas A&M University's Conservation Research Laboratory has been engaged in a comprehensive survey of past research and recommendations for future conservation work of the saltpeter remains at Mammoth

Cave. In this report, we provide a summary and timeline of the development of the saltpeter mining operation in the early nineteenth century. We conclude with a discussion of future work to provide additional documentation of the remains and improve interpretive materials for the National Park Service.

While there is no single source that describes the engineering aspects of the saltpeter operation in its entirety, there are a number of general descriptions of the works at the time it was in operation and descriptions of the remains by various visitors to the cave after the operation ceased. We have compiled a reference list of more than 200 sources (written descriptions, photographs or drawings, and maps) that refer to the Mammoth Cave saltpeter operation, technical discussions of saltpeter manufacturing that would apply to Mammoth Cave in the early 1800s, or results of research on the operation. Among the early descriptions of the cave, one of the best sources is an account written by Robert Bird (already quoted above), published originally in the *American Monthly Magazine* in 1837 and reprinted in 1838. The so-called Eye-Draught Map of Mammoth Cave of 1811 drawn by Frederick Ridgely (see George 2001) and the 1835 Lee Map are also extremely useful for information on the saltpeter works. Numerous other published letters and descriptions refer to the saltpeter works and some contain unique information; however, these tend to be redundant, often based on previously published descriptions.

Interest in the saltpeter works as a historical resource began in the 1940s. Thor Borresen (1941), an Assistant Historical Technician with the NPS, produced a report on the remains in 1941 that made several recommendations for preservation of the remaining works. He also made the first detailed technical drawings of the extant remains. (His original drawings were later redrawn and adapted as part of a Historic American Engineering Record project [Mullin 1986].) The classic study of saltpeter mining in Mammoth Cave is by Burton Faust (1967), originally published in the *Filson Club History Quarterly* and later reprinted. In the 1970s and early 1980s, Duane De Paepe re-examined the saltpeter remains and did extensive historical research on the operations. This work culminated in a well illustrated book for the general public (De Paepe 1985). More recently, Angelo George has published several well researched books and articles on various aspects of saltpeter mining at Mammoth Cave and elsewhere (e.g., George 2001, 2005). Beginning in the mid-1990s, various archaeological projects related to the Historic Entrance Ecotone Restoration Project, new lighting and walkway construction projects, and the NPS-Earthwatch cultural resources inventory have documented other aspects of the mining works through excavation and survey (e.g., Crothers 1996; Mickelson 2008). Examination of all of these resources – early descriptions, historical research, and archaeological work – has allowed us to construct a fairly detailed outline of the saltpeter operation and subsequent development impacts.

Niter Production at Mammoth Cave

At the peak of production, sometime between 1810 and 1814, the Mammoth Cave operation was extensive. In the cave, it consisted of three hand pump towers, at least 3400 feet of wooden pipeline for bringing water into the cave and nitrate in solution out of the cave, ten leaching vats to extract nitrate from the cave sediments, an 1800 foot long hard-packed ox-cart trail to move large loads of sediment in the cave, up to two miles of mined cave passageway, and a work force of up to 70 men, mostly composed of slave labor. Immediately outside of the entrance, additional processing of the calcium nitrate solution was done to convert it to potassium nitrate, purify, and evaporate the water in a large boiling furnace to produce saltpeter crystals. In addition, on the ridge above the cave entrance there were living quarters for the laborers and managers. The operation had to be supplied by a steady stream of firewood and potash from the surrounding area. Lastly, the final product was packaged and shipped, primarily by overland routes, to eastern gunpowder mills. Although the wooden remains – hoppers, pipes, and pump towers – are the most conspicuous elements of the operation, remains of or archaeological evidence of nearly all of the components of the operation may still be found in the cave. We discuss the elements of the mining operation in the following order: sediment extraction, leaching vats, ox-cart trail, pumps and pipeline, and boiling furnace.

Sediment Extraction

The best sources in the cave for nitrates are clay deposits where water no longer drips or percolates. Sandy sediments, which can be found underlying the clay for an undetermined depth, were not found to be nitrate rich (notes on the Eye-Draught map). The clay, which could be found in the upper few feet of sediment strata, was distributed throughout the cave but often lay beneath cave breakdown. This required removal of large amounts of breakdown and in several places stacked rock walls can be found that were removed to get at the underlying clay. This handy work is well preserved in Cyclops Gateway and Gothic Ave. or Haunted Chambers. An extremely good example of a mining pit can be seen opposite of the Church just behind the in situ water pipes and stone piers.

Leaching Vats

Leaching or lixiviation of the cave sediment was done in wooden vats. Large square vats are generally considered characteristic of large scale operations and V-vats of smaller operations. Square vats were constructed in two areas of Mammoth Cave: the Rotunda or Big Room and at Booth's Amphitheater or the Grand Gallery. These vats are in various states of disrepair, some still containing their last load of sediment. They represent the end stage of the mining operation in 1814 or 1815. It is not clear when saltpeter mining began at Mammoth Cave, but it may have been as early as the late 1790s. However, this would have been a much smaller operation. It appears that the first vats were constructed at the entrance of Mammoth Cave and sediment was hauled from inside the cave to be processed near the spring. The Eye-Draught map of 1811 appears to show leaching vats in the entrance, but no vats in the Big Room or the Grand Gallery. Perhaps the Eye-Draught map was drawn earlier and later sent to various parties. At least two versions of the map survive with different handwritten notes (George 2001:14-15). These early vats in the entrance may have been V-vats. A drawing of the entrance on the Lee map appears to show the bottom member of a V-vat remnant. Portions of wood debris now stashed in the Rotunda appear to be parts of V-vats, perhaps salvaged and later carried into the cave.

It is not clear when the first square vats were constructed in the cave, but it would seem to be sometime after 1810. An extract of an undated letter by John Farnham (1820), describes square vats in the cave for leaching nitrate that was then conveyed by pipes "as near as possible to the entrance of the Cave, whence it is taken by buckets to some convenient place above ground, and put into boilers, . . ." (Farnham 1820: 357). Presumably this refers to the Rotunda or first hoppers. It is interesting that no pump tower appears to be at the entrance at this time. Farnham (1820: 358) later describes ascending a "plank bridge" into the haunted chambers, but mentions no vats or pipes at this location. Farnham would appear to have visited the cave sometime between 1810 and 1812 when the first hoppers and pipeline were built in the

Rotunda, but before the second hoppers or the entrance pump tower were constructed.

Ox-Cart Trail

The ox-cart trail may have been the first major modification to the cave for the purpose of mining. Eventually, the trail extended all the way from the entrance to just beyond the second hoppers. Here the oxen were tethered and fed. It is not clear how much farther the trail went into the cave because the modern tourist trail is built on top of any previous ox-cart trail. The first portion of the trail, however, was built through the Narrows. The passage was originally a low stoop way strewn with breakdown (Crothers 1996). A narrow path was made through the breakdown by stacking rock to the sides until a layer of thickly bedded sand was encountered and it was wide enough to admit an ox-cart. It is possible that the ox-cart trail was first constructed through the Narrows to bring sediment out of the cave for processing at the entrance, and only later a pipeline added when leaching was moved into the Rotunda. Excavations in the Narrows indicated two layers of trail construction: an older trail-bed under laying the wood pipe line and upper trail-bed incorporating the pipeline (Crothers 1996:4). Eventually, the ox-cart trail was extended through Main Cave, mainly hugging the left wall of the cave going in. The trail is still well preserved through this section of the cave until it merges with the modern trail at Kentucky Cliffs; however, rock has been placed on the trail to hide its presence.

Pumps and Pipeline

The pump and pipe system was an engineering feat. One set of tulip poplar pipes transported fresh water from the entrance spring to the first and second hoppers for leaching. A second set of pipes with the help of pumping stations carried the dissolved nitrate solution back to the entrance by a gravity feed. The towers in Booth's Amphitheater and the Rotunda raised the solution by a suction/lift pump to a height that would allow it to flow by gravity to a reservoir at the next pump station (Mickelson 2008). At the entrance, a third pump tower lifted the solution over the lip and by pipe to the boiling furnace. The pump tower at the second hoppers is the most complete, but it has been dismantled and incorporated into an old hand railing (no longer used). The pump tower at the first hoppers is mostly destroyed, but three of the legs are still partially intact in their original footing and the main body of the pump, recently damaged by rock fall, has survived. The tower at the entrance is now gone, but two long hand hewn square timbers in the Rotunda appear to be tower supports, possibly from the entrance pump frame (De Paepe 1975: 68). The drawing on the Lee map (1835) shows cross-member supports for this framing system still in place across the entrance.

Three portions of the pipeline remain intact, and dismantled pipes are strewn through the cave. The first and longest intact section is a dual pipeline through the Narrows, which commences just inside the entrance, hugs the right wall, where it is now protected behind a hand railing and is incorporated into the old ox-cart trail, but eventually merges with and lies under the modern trail into the Rotunda. The second intact section is a short section of dual pipes built on piers at the edge of the Church. This section of pipe is severely compromised by fungal growth from the old lighting system and is in need of immediate conservation. The third intact section of pipe is a single water pipe on a stone pier that is buried in the modern trail below Kentucky Cliffs. Discovered during an archaeological testing project for the boardwalk construction, it was apparently intentionally buried when the CCC trail was built in the 1930s (Crothers 1996). Bases of two stone piers along the ox-cart trail between the first and second hoppers suggests that the demolished section of pipeline followed the oxcart trail and was dismantled when the trail was covered with rock by CCC workers in the 1930s (De Paepe 1975: 68).

Boiling Furnace

Very little is known about the construction of the boiling furnace, although the furnace chimneys stood for many years and piles of ash were noted by early visitors. An undated map of the furnace foundation in possession of the Park Service shows its location relative to the entrance, but no systematic attempt has been made to document the foundation more thoroughly. The modern road has probably compromised part of this feature, but additional archaeological work will be necessary to assess its integrity.

Future Work and Conservation Efforts

A comprehensive list of recommendations for additional documentation, both archival and by archaeological means, is being prepared for the NPS. This will include additional documentation of the remains found in the cave that will allow a virtual reconstruction of the operation at its peak phase of production. This will build on the earlier work by Borresen (1941) and the HAER project (Mullin 1986). Those portions of the remains that were dismantled and repurposed in the cave as hand rails, trail borders, and other uses should be removed, conserved if necessary, and placed in a location safe from the reach of tour groups. The rock which was placed on the ox-cart trail should be removed and this feature interpreted as a historical feature of the cave. We do not recommend reconstructing portions of the works in the cave that have deteriorated or been demolished, but replicas showing early nineteenth century craftsmanship and engineering of the vats, pipes, or pumps could be erected at the visitor center as interpretive displays. Some remains will be recommended for removal and conservation in laboratory conditions and then returned to the cave. This could include the lone remaining pump body and other unique pieces of the works. Environmentally friendly conservation treatment will be recommended for in situ remains to kill fungal growth, but the advance stage of dry rot on many pieces may be beyond salvage at this point. That is why thorough documentation of the remaining pieces is necessary now before even more information is lost.

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Archaeological Evidence of Historic Mining at Forestville Saltpeter Cave (15Ht94), Hart County, Kentucky

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Abstract

Forestville Saltpeter Cave is 1.5 km east of Mammoth Cave National Park on the WKU Green River Preserve. Historically, miners removed sediment from the cave to extract saltpeter for the production of gunpowder. Though dozens of peter-mining sites are known in western Kentucky, Forestville Saltpeter Cave is only the third site investigated by archaeologists. Intensive surface survey documented evidence of mining activity in the cave: working bays, rock piles, tally and other marks, tool marks, inscriptions, and lighting material. The mining likely occurred during the early nineteenth century. The operations were extensive throughout all passages and extracted 856 cu m of sediment.

Introduction

Potassium nitrate is a compound used in fertilizer, food additives, and fire suppressants, though it is perhaps best known as an essential component of gunpowder. Potassium nitrate can be manufactured by combining manure or urine with wood ashes or mortar, or it can be extracted from guano deposits. Alternatively, potassium nitrate occurs as nitre, a water-soluble mineral that crystallizes in arid environments such as sandstone caves and rockshelters. The bedrock and sediments of some limestone caves and rockshelters contain a similar water-soluble mineral, calcium nitrate or saltpeter, which can be converted to potassium nitrate through a series of chemical processes and then combined with sulfur and charcoal to produce gunpowder (Faust 1967; George 1986, 2001, 2005).

Nitre/Saltpeter and gunpowder (black powder) were essential commodities on the American frontier. Though Americans imported most of their supplies in the late eighteenth and nineteenth centuries, they were forced to produce them domestically in remote locales and during times of conflict. The era of most intensive domestic production was in the early 1800s, especially before and during the War of 1812. About 90% of the gunpowder used in the war was produced with nitre/saltpeter from Kentucky. Nitre/Saltpeter mining occurred on various scales in Kentucky, ranging from small-scale family operations or cottage industries to large-scale industrial operations (Faust 1967; George 1986, 2001, 2005; O'Dell 1995).

Despite the key role that Kentucky played in supplying the fledgling nation with nitre/ saltpeter, there have been few archaeological studies of this important industry (O'Dell 1995). In the recently revised Kentucky state archaeology plan, McBride and McBride (2008:988) reported a total of 125 nitre/saltpeter mining sites in Kentucky's caves and rockshelters, and 124 of these are located in the Appalachian cultural landscape of eastern Kentucky. Only one such site, Mammoth Cave (15Ed1), is identified in the Pennyrile cultural landscape of western Kentucky. Not only is the spatial coverage of recorded sites limited; the number of archaeological investigations of these nitre/saltpeter caves and rockshelters is equally limited. In western Kentucky, archaeologists have conducted research at only two sites: Mammoth Cave (Crothers et al. 2013, Mickelson 2008) and Carpenter Cave (15Al22) in Allen County (Henry and Crothers 2007). In eastern Kentucky, Duncan (1995, 1997) studied Saltpeter Cave (15Cr99) in Carter County, and Webb and Funkhouser (1936) and Fig and Knudsen (1984) reported on rockshelter nitre mining sites.

In contrast, speleologists have reported evidence of nitre/saltpeter mining in numerous caves (and some rockshelters) across the Commonwealth. Angelo George, for instance, identified 133 caves and six rockshelters in Kentucky that are known or suspected nitre/saltpeter mines. They are clustered along the western edge of the Cumberland Plateau in eastern Kentucky and in the central part of the Mississippian Plateau in western Kentucky. Of the 139 sites, 56 are located in an 18-county region centered on Mammoth Cave (George 1986a). Further, speleologists have written in detail about the mining industries at a number of nitre/saltpeter mining sites, such as Mammoth Cave (De Paepe 1985; Faust 1967; George 2001, 2005; Hill and De Paepe 1979), Great Saltpeter Cave in Rockcastle County (George 2001), and Dixon Cave (15Ed225) in Edmonson County (George 1986b, 2005).

Given the abundance of nitre/saltpeter mining sites in Kentucky yet the paucity of archaeological documentation and investigations of these sites, especially in western Kentucky, the current research project sought to explore in detail archaeological evidence of saltpeter mining in a Hart County cave. In contrast with nearby Mammoth Cave and its industrial saltpeter manufactory, Forestville Saltpeter Cave affords an opportunity to study smaller-scale nineteenth century saltpeter mining in western Kentucky. The project was guided by three research questions: What is the archaeological evidence of saltpeter extraction in the cave? When did the mining activity occur? What was the extent of the mining activity? Our field methods involved systematically surveying the ground and rock surfaces within the cave, mapping the mining activities, and verbally and photographically recording evidence of historic mining.

Site Description and Previous Investigations

Forestville Saltpeter Cave (15Ht94) is situated in a very steep cut bank on the north side of Green River in the WKU Green River Preserve in Hart County, about 1.5 km east of the northeastern boundary of Mammoth Cave National Park. The entrance is located at 550 ft amsl, about 130 feet above normal river pool and 250 ft below an unnamed ridgetop (Figure 1).

The horizontal passageways of Forestville Saltpeter Cave formed in the upper Ste. Genevieve limestone formation (Sandberg and Bowles 1965). Based on the original level of the cave sediments, which is indicated by discolorations on the cave walls, the passages were substantially infilled prior to the saltpeter mining. As such, the original ceiling height in the cave was quite low and would have limited movement by the miners.

The large cave entrance measures about 11 m wide and five m high and opens into a similarly sized vestibule. James Borden and Joseph Saunders of the Cave Research Foundation mapped the cave in 1974 (Figure 2). The passages in the single-level cave total 522 m in length. The terminal passage and four side passages end in fill, while a fifth side passage was mapped to the point that the ceiling was too low to pass (Borden and Saunders 1974). During this mapping expedition, Borden and Saunders “found a saltpeter scoop, 1812 vintage, in the cave” (Saunders et al. 1979:5). No other details about the artifact, including its form, discovery context, or current location, are known.

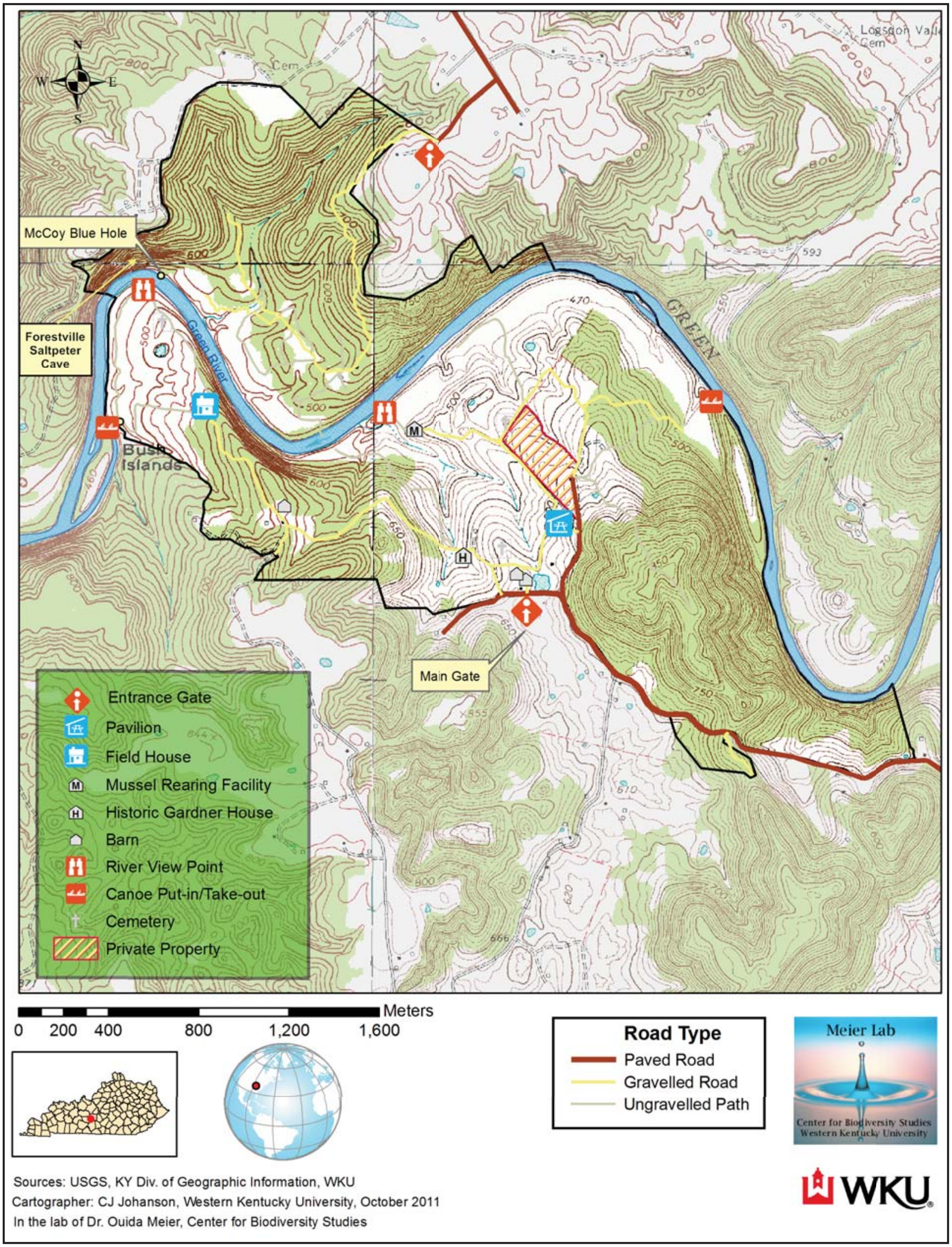

Figure 1: Topographic map composite showing location of Forestville Saltpeter Cave on Cub Run (1979) 7.5-minute quadrangle within the boundary of the WKU Green River Preserve (map courtesy of Dr. Ouida Meier, Western Kentucky University).

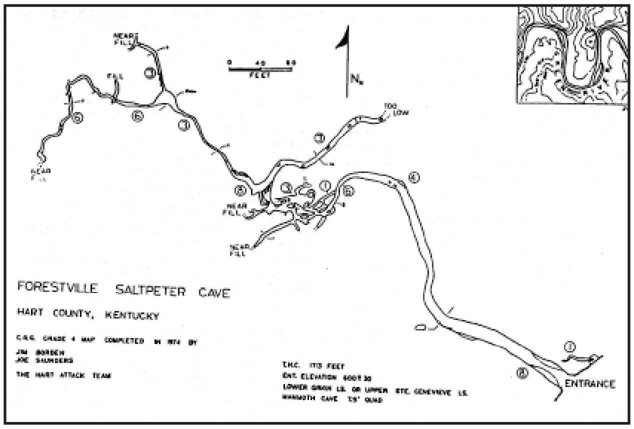

Figure 2: Plan view map of Forestville Saltpeter Cave (Borden and Saunders 1974).

Speleologists Larry McCarty, Pat Stephens, Angelo George, and Charles B. Fort studied the cave on two occasions in 1985. George (1985) wrote a brief description of saltpeter mining at Forestville Saltpeter Cave. He noted excavation trenches, stacked rock piles, wooden torch fragments, lamp seats, linear tally marks, and "exotic" tally marks including an asterisk form (which may be a slave cosmogram [George 2005:18]), circle with cross, and half-circle with radiating tallies. As there currently is no water source in the cave, George hypothesized that the miners used a shoot or a wire line to transfer bags of sediment to the river floodplain for processing. However, he also noted that some maze passages were "backfilled with processed saltpeter earth for re-nitrification to occur" (George 1985:15), which suggests that processed sediment was transported back to the cave and/or some sediment was processed on-site. George (1985:16) concluded that miners preferred Forestville Saltpeter Cave, like other maze-passageway caves, because "the saltpeter content was stronger and probably re-nitrified faster."

Evidence of Saltpeter Mining

Regarding the first research question, we documented considerable evidence of sediment mining activity at Forestville Saltpeter Cave. The most obvious evidence is the working bays where the peter-laden soil was mined. A working bay is a "cavity produced by the mining of soil . . . identifiable as a niche in a soil bank bounded on three sides by a high wall excavation face" (George 1986b:96). Working bays are present throughout all passages within the cave, where their dimensions vary depending on the depth of the cave sediments and the size of the cave passage. There was extensive sediment mining in the vestibule of the cave, where a medial trench measures as much as four m wide and three m deep (though it is possible the entire vestibule was mined and the trench represents a trail between lateral piles of re-deposited processed sediment). Midway through the trunk passage the face of the excavated sediment is as much as four m high (Figure 3). The miners also removed sediment from lateral ledges along the trunk passage in the vestibule. The ledges are one-two m above the current cave floor, but they likely were below the floor of the infilled cave prior to mining. As such, the ledges were exposed by the mining and do not represent balcony alcove working bays (c.f., George 1986b).

Figure 3: Vertical face of working bay along north wall at 120 m from cave entrance.

Another indication of the mining activity is rock piles resulting from two mining-related activities. As the miners excavated the cave sediments they encountered rocks that had previously fallen from the cave ceiling. They piled these rocks on ledges and on previously mined surfaces as they worked through the cave passages. The rock piles also resulted from clearing pathways to facilitate the movement of miners and their equipment within the cave. There are 11 major rock piles in the trunk passage and north side passage. They range from 1.2 x 1.0 m to 9.0 x 3.2 m in size.

Tally marks represent a third line of evidence of the mining activities at Forestville Saltpeter Cave (Figure 4). The marks are scratched or incised into the rock of the cave walls. The typical form of the tally marks is vertical lines, which can be long or short, thick or thin, shallow or deep. Some tally marks have horizontal or angled incisions across the vertical lines. There are 66 sets of tally marks, and an additional ten possible sets, throughout all passages of the cave. The number of lines within any one set ranges from 2 to 30. We recorded at least 631 tally marks associated with the mining activity at Forestville Saltpeter Cave.

Figure 4: Set of 15 vertical tally marks in the south wall of the trunk passage at 162.7 m from the cave entrance.

Saltpeter miners likely used tally marks as a counting system to track the amount of excavated soil or processed soil (Faust 1955), and Blankenship's (2008) research at Cagle Saltpeter Cave in central Tennessee demonstrated a correlation between tallies and mining rather than tallies and leaching.

We documented 21 directional arrows on cave walls in the trunk, north side, and north terminal passages. Twenty of the arrows are incised, and one is formed by candle marks. The arrows point in the direction of the cave entrance and are found primarily in the deeper maze passages. We propose that most of, if not all, the directional arrows were left by the miners as they explored and mined the cave, so they could find their way out.

In addition to the tally marks and arrows, we found a number of other incised symbols, at least some of which may be associated with record keeping by the miners. Four crosses are incised in the three locations within the north side passage. The trunk and north side passages each contained two incised cross hatches, each of which is formed by two horizontal lines and two vertical lines. Eight incised X marks are located in the trunk, north side, and north terminal passages. Eleven asterisk marks, each of which is formed by four intersecting lines, were found in three places: single asterisk marks in the trunk and north side passages and a series of at least nine superimposed asterisk marks in the north terminal passage. The "asterisk" is the symbol that George (2005:18) suggested may be a slave cosmogram. Other symbols are a sun form (circle with short radiating lines) in the trunk passage and a cross inside a circle and an L form in the north side passage. Other unpatterned incised marks are found in at least 11 places of the trunk, north side, and north terminal passages.

A sixth line of evidence about the historic mining is tool marks. These are impact scars, chips, and wide scratches on rock surfaces, as well as wide scratches and gouges in the unexcavated cave sediments. Based on the sizes of the tool marks, they likely were made by metal tools, possibly picks, mattocks, shovels, and/or spades. There are hundreds tool marks on the cave walls and sediment faces throughout all passages of the cave. We found no evidence of the use of digging sticks (Faust 1955).

There are five other types of evidence potentially related to mining operations at Forestville Saltpeter Cave, though it is likely that some derive from other cave visitors. There are 102 historic inscriptions on the cave walls and ceiling throughout all passages. Some of the inscriptions are decipherable and many are illegible. The inscriptions include names, initials, dates, and words like "HELP." Name signatures were made by incising with a sharp tool or, more commonly, with charcoal (Figure 5) or candle/torch smoke. Several contemporary signatures are in crayon and chalk. Nine inscriptions are dates or include dates ranging from 1872 to 2004, though one somewhat illegible date may be 1811, 1852, or 1854 and another may be 1860. The inscriptions with the nineteenth century dates are located near the end of the northern terminal passage, in the vicinity of another inscription reading $40,000.

Figure 5: Undated charcoal signature of L. F. Philpott on the ceiling of the trunk passage at 90.0 m from the cave entrance. The Philpott family has a connection to property in the vicinity of Forestville Saltpeter Cave. Around the turn of the twentieth century Curtis C. McCoy married Martha E. (Philpott) McCoy and the family resided in the Forestville area until at least the 1930s. In the early twentieth century Curtis McCoy's parents, Washington Alexander and Dilemma (Ewing) McCoy owned the farm on which the cave is located (Applegate 2007).

The other four cultural items that may be mining-related are associated with lighting. A total of 39 isolated candle marks and charcoal/torch marks are found on the cave walls and ceilings throughout all passages, especially the trunk and south terminal passage. The candle marks take the form of small circles, squiggles, and amorphous shapes, and at least some of the charcoal marks appear to be torch stoke marks. A few of the candle and charcoal marks are associated with tally marks. Four possible lamp seats were recorded in the trunk, north side, and north terminal passages. Finally, we documented nine pieces of burned wood on the cave floor, with seven in the trunk passage and one each in the north side and north terminal passages. Most of the burned wood is short or long segments of tree branches that were carbonized at one end, indicating their use as torches for lighting. Several amorphous pieces of burned wood likely fueled small fires in the cave.

In terms of sediment processing, we found no evidence of on-site leaching within the cave or immediately outside the cave entrance. There are no water pipes, vats, or other equipment that would have been used to leach the saltpeter. Further, we currently have no evidence to support George's (1985) hypothesis about floodplain processing, though the changing river levels could have obliterated any such evidence. It is also possible that sediment was loaded onto river flat boats and transported elsewhere for processing.

When the Mining Occurred

Regarding the timing of the mining activity, at this time we lack adequate data to say with certainty when the mining occurred, over what length of time, and by whom. Unfortunately, the historic inscriptions with dates are non-conclusive, as it is unclear whether they were made by miners or other visitors. Nor did we recover any chronologically diagnostic artifacts from the cave that we could use to date the mining operations, though we may seek radiocarbon dates for the burned wood in the future.

Based on the time period of saltpeter mining at nearby Mammoth Cave, where mining ended in 1815, we propose that the mining at Forestville Saltpeter Cave similarly occurred in the early nineteenth century. The possible incised date of 1811 may support this hypothesis, as would the 1812-vintage saltpeter scoop reported by (Saunders et al. 1979:5). The fact that nitre/saltpeter mining in Kentucky occurred primarily in the late 1700s-early 1800s (De Paepe 1985; Duncan 1995; 1997; Faust 1967; George 2001, 2005; Hill and De Paepe 1979; O'Dell 1995) makes it likely that Forestville Saltpeter Cave was mined during the same time frame. Though some nitre mines resumed operation in eastern Kentucky during the Civil War (McBride and McBride 2008), most researchers (e.g., Tabor 1942, O'Dell 1995) concur that little saltpeter was produced in Kentucky during that conflict.

It is possible that local residents conducted the mining activities at Forestville Saltpeter Cave in order to manufacture their own supplies of gunpowder or to preserve meats. The land south of the cave across Green River was settled as early as 1796 (Applegate 2007), and at that time the inhabitants of this new frontier may have been far enough removed from commercial ties with the East that they could not purchase gunpowder. It is perhaps more likely, however, that the mining operation at Forestville Saltpeter Cave was a commercial venture, given the large amount of sediment that was removed, as described below.

The Extent of Mining Activity

The mining operation at Forestville Saltpeter Cave was quite extensive and occurred along all navigable passages within the cave. Besides removing sediment from the main passage and the smaller side passages, the miners crawled into a number of very low recessed areas off the passages in order to remove sediment. Some of these spaces are so constricted that it is difficult to imagine an adult maneuvering with his tools to excavate the sediment.

We measured the excavated portions of the cave sediments in order to estimate the volume of material removed by the nitre mining operations. The miners excavated at least 856 cu m of soil, which is comparable to almost 24,000 bushels (O'Dell 1995; Duncan 1995; 1997). Assuming that each bushel weighed three-five pounds, this is 72,000 to 120,000 pounds of sediment, all of which apparently was processed somewhere offsite. About 80% derived from the trunk passage and 20% from the side passages. Assuming that each bushel of sediment from Forestville Saltpeter Cave produced at least 10 pounds of saltpeter, a conservative estimate (O'Dell 1995), the cave would have generated at least 2,400 pounds of saltpeter. By comparison, in 1810, a total of 2,250 pounds of saltpeter was produced in all of Hardin County (Coxe 1814), in which Forestville Saltpeter Cave was located at that time.

This estimate is astounding. By comparison, Duncan (1995, 1997) estimated that early nineteenth-century miners excavated about 52,000-86,000 pounds of sediment at Saltpeter Cave, which is considered moderate-sized operation. Our estimate for Forestville Saltpeter Cave exceeds this by 20,000-34,000 pounds. Of course, the mining at Forestville Saltpeter Cave does not approach the scale of that at Mammoth Cave, where about 400,000 pounds of saltpeter was produced during the War of 1812 (De Paepe 1985; Faust 1967; George 2001, 2005). Still, at the conservative pre-war price of 16.7 cents per pound (Coxe 1814) the operation would have generated about only about $400 in income. At the war-time high price of 75 cents to one dollar per pound (O'Dell 1995), however, the value could have been as much as $1,800 to $2,400.

Conclusion

In conclusion, the archaeological investigations at Forestville Saltpeter Cave documented diverse evidence of extensive mining activities that likely occurred in the nineteenth century. This evidence includes working bays, rock piles, tally and other marks, tool marks, inscriptions, and lighting material. The research is significant because it is the only the third archaeological investigation of saltpeter mining in western Kentucky, and because it indicates an extensive mining operation in cave that is very difficult to access. With many more known saltpeter cave sites in western Kentucky, there is still a great deal to learn about this important early industry in the state.

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Archaeological Investigations for Proposed Trail Rehabilitation within Mammoth Cave

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Abstract

In 2008, staff from the University of Kentucky Program for Archaeological Research (UK-PAR) and the Illinois State Museum Society (ISMS) conducted archaeological and paleontological investigations at Mammoth Cave National Park in advance of proposed rehabilitation of 40,499 linear feet of selected trail segments within Mammoth Cave. This presentation focuses on the results of archaeological investigations conducted within Mammoth Cave and is confined to discussion of the prehistoric materials. These materials were confined to the upper and lower passages of the Historic Tour, the Lantern Tour, and Gothic Avenue trails (Figure 1)

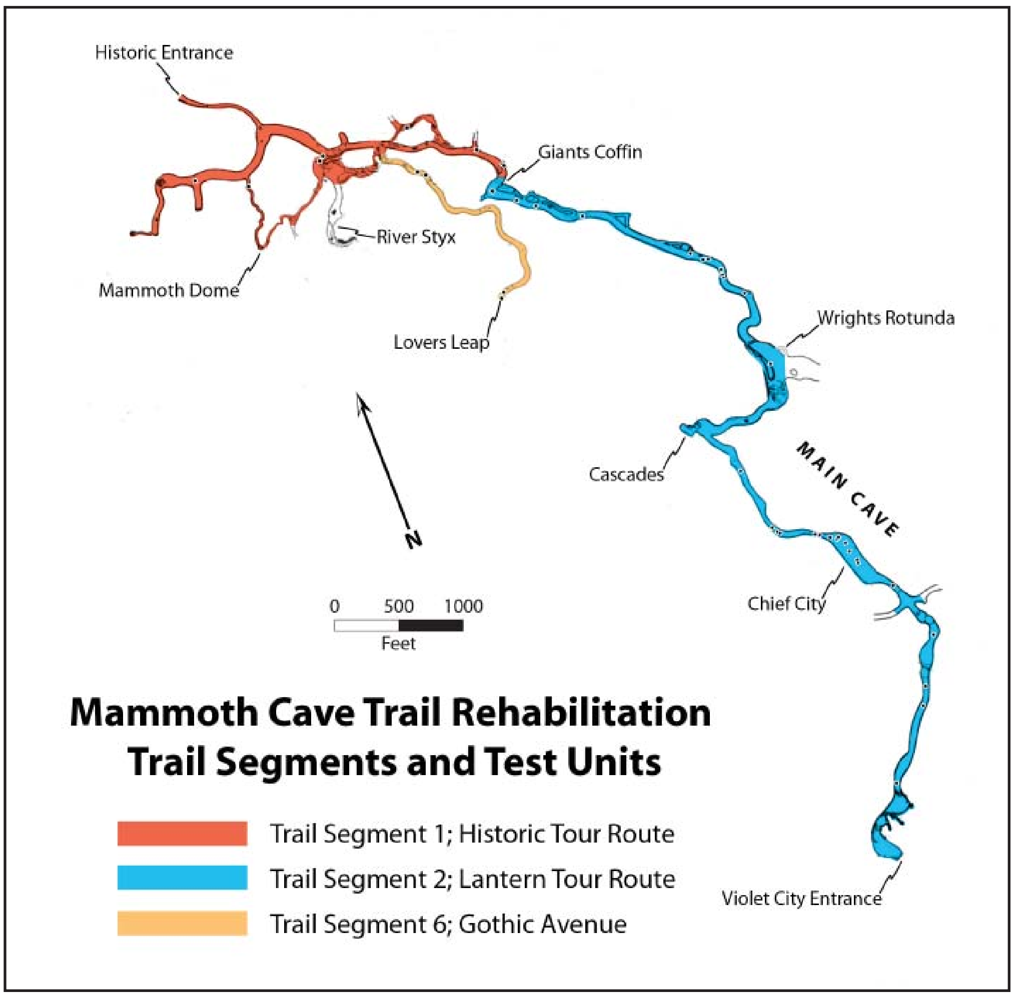

Figure 1: General Map of Upper Levels of Mammoth Cave System showing Selected Trail Segments Targeted for Rehabilitation. General test unit locations are shown as black squares with white borders. Small side passages are not shown.

Previous Research

Though the entrance rooms of many caves and rock shelters in the eastern United States show evidence of both short-term and long-term use beginning in the late Paleoindian period (ca. 9000 BC) and continuing through the prehistoric era, the earliest known evidence of cave dark zone exploration has been documented at sites in Tennessee (Simek et al. 1998; Watson et al. 2005), Indiana (Munson and Munson 1990), and Kentucky (Watson 1997a; Watson[editor] 1997). It appears that the purpose of these early activities was simply exploration, which left subtle traces in the form of torch charcoal, smudge marks, and human footprints. Jaguar Cave in Tennessee has produced the earliest dates for dark zone exploration, between 3520 and 3110 BC, in the Middle Archaic period. Although 3rd Unnamed Cave, Wyandotte Cave, and Mammoth Cave each also have a few early dates, the large majority of assays date to later periods.

Activities conducted in these caves include quarrying of high-quality chert, mining of aragonite, and in Mammoth Cave, mining of gypsum, selenite, mirabilite, and epsomite. These mining activities in Mammoth Cave primarily date to the Early Woodland period, 1000 to 200 BC (Crothers et al. 2002). Other temporal periods are apparently not represented, though cave use was also common in the midsouth between AD 1000 and 1550. Prehistoric gypsum mining is not limited to Mammoth Cave, but it is very well documented. Where gypsum has formed, it has been extensively pounded and scraped from the walls and ceiling where it is reachable, and the selenite form has been dug from remnant cave fill sediment. There is almost no portion of upper Mammoth Cave within several kilometers of the historic entrance that was not intensively mined. Gypsum was most likely ground and used as a white pigment. Mirabilite and epsomite are more localized in their occurrence within the cave system. Both minerals create soft frost-like coatings on cave wall surfaces and may accumulate on the floor. Both minerals are well-known as intestinal cathartics. The large number of desiccated human paleofeces found in Mammoth Cave suggests that this use was well understood by prehistoric cavers, and the salts were consumed in the cave for their effect.

Any activity conducted remote from the natural entrance of any cave requires artificial light. The most common evidence for prehistoric use of the dark zone is the torch debris left behind. The most common material for torches was river cane (*Arundinaria gigantea*), though a variety of other woody materials was used. Also commonly recovered are the plant fiber ties for torch bundles. Torch remains, both carbonized and uncarbonized, are ubiquitous through most of the upper-level passages that have not been disturbed by later activity. Any other material brought into the cave presumably had a specific purpose, as cavers would not want to be encumbered with unnecessary items. The mining activity in Mammoth Cave used simple expedient tools, such as digging sticks, mussel shell scrapers, hammerstones, gourd and wooden bowls and basketry for collecting minerals. Fragments of cordage and textile may be the remains of carrying bags or parts of clothing.

The single largest category of material exclusive of torch debris is human paleofeces. Hickory nut (*Carya* sp.), sunflower (*Helianthus annuus*), annual marshelder or sumpweed (*Iva annua*), pitseed goosefoot (*Chenopodium berlandieri*), maygrass (*Phalaris caroliniana*), and occasional squash (*Cucurbita pepo*) seeds apparently made up significant portions of the diet during the Early Woodland period. With the exception of hickory nutshell, all of these seed remains are components of the Eastern Agricultural Complex, a group of early plant domesticates used in eastern North America (Smith 1992). Aside from those found in paleofeces, subsistence remains are extremely rare in Mammoth cave. In the dark zone, no prehistoric ceramics have been found, and evidence for lithic reduction and toolmaking is very scant, in contrast to contemporary open sites. Systematic survey of the upper passage of Mammoth Cave showed that paleofeces were not randomly distributed, but instead were concentrated near abundant sources of mirabilite and epsomite (Crothers 2001), supporting the hypothesis that ingestion of medicinal salts in the cave was at least one of the reasons for the intense prehistoric utilization. Analysis of the steroids preserved in paleofeces has demonstrated that the prehistoric defecators were exclusively male. Combining these observations, Crothers (2012) hypothesized that caves like Mammoth and Salts may have functioned primarily as sites for performing rites of passage of young males into adulthood, with the cave environment and its mineral resources comprising important aspects of Early Woodland rituals.

Based on this previous research, specific research objectives were developed that included:

1) obtaining additional radiocarbon dates to verify primarily Early Woodland activities, or alternatively, to demonstrate that the cave was used during other time periods;
2) collecting materials from intact excavated contexts;
3) determining the types of activities conducted within the cave;
4) assessing the evidence for prehistoric activities besides mineral mining;
5) examining the spatial distribution of prehistoric materials to identify locations where specific activities took place; and
6) providing recommendations for minimizing impact to archaeological deposits with high research potential.

Methods

Field work began with a detailed walk-through and visual examination of the trails targeted for rehabilitation. Trail segments that contained thick trail construction fill, had been excavated to basal cave sediments, were severely disturbed by historic saltpeter mining, or were too moist to preserve uncarbonized plant remains were identified and excluded from further consideration. This initial triage excluded most of the Gothic Avenue trail and large segments of the upper level of the Historic Tour trail. Some of the upper Historic Tour had also been previously investigated in advance of installation of new electric lighting. Locations with high archaeological potential were identified based on previous survey, test excavation, and surface collection work. Archaeological test unit excavation was thus limited to the most productive, representative, previously uninvestigated, or potentially important locations.

All test units were confined to the existing trail and a 1.5-foot wide buffer on each side of the trail that will be directly impacted by trail rehabilitation activities. Previous excavation experience within Mammoth Cave led us to expect to encounter specific strata. Though there was considerable variation, especially in test units that encountered guano deposits, the typical stratigraphic sequence for archaeological deposits consisted of an upper Stratum I of historic trail sediments deposited when the trail was constructed by the CCC in the 1930s. This is underlain by Stratum II, an anthropogenic deposit of mixed carbonized and uncarbonized material distributed above, among, and below rock fall (Figure 2). Some units encountered basal cave fill

Figure 2: Example Test Unit Profile (Test Unit R4) showing Typical Sequence of Stratum I Trail Construction Sediments over Stratum II Intact Anthrpogenic Sediments. Stratum II is interspersed with rock fall. Note dark surfaces on rocks within Stratum II and lighter, fresh surfaces on smaller rocks that comprise the Stratum I trail fill.

sediment, but most often, excavation was halted because no additional rock fall could be removed. All units were excavated by natural strata when these could be identified, with sediment screened through ¼-inch mesh to collect artifacts and other prehistoric debris. After excavation halted, two adjacent profiles were documented, and test units were backfilled to original contour.

Five test units were placed on upper-level portions of the Historic Tour trail, four on the lower Historic Tour trail, four on Gothic Avenue, and 29 along the Lantern Tour (Figure 1). The units in Gothic Avenue produced very little archaeological material and are not discussed further. Units on the Historic Tour and Lantern Tour routes produced the bulk of material and provide the basis for the majority of the interpretations.

Findings

Principal findings from the project allow us to partially address the research questions outlined above. Eight additional radiocarbon assays derived from various test unit locations confirm that prehistoric use of Mammoth Cave is temporally restricted to the Terminal Archaic and Early Woodland periods, between about 2175 and 3400 years BP. Additional analysis suggests that age is positively correlated with distance from the historic entrance, which is somewhat counterintuitive. However, the correlation is relatively weak, and as usual, we would like more data.

Abundant archaeological remains were recovered, but they were not distributed evenly among the test units. The materials collected from prehistoric contexts were dominated by torch debris (n=1359), while prehistoric artifacts modified by human use were comparatively rare. Artifacts were limited to torch ties (n=236), cordage (n=30), expediently utilized sticks (n=20), lithic debitage (n=8), and a mussel shell. As expected, no prehistoric ceramics were found. This strongly supports the inference that the prehistoric activities carried out in the dark zone in Mammoth Cave were not typical of ordinary household activities, but are related primarily to mining minerals, likely for ritual purposes.

Subsistence remains (n=483) were relatively abundant, but were limited to botanical remains. This total includes chenopodium, maygrass, panic grass, sunflower, marshelder, and gourd seeds, plus nutshell and grape stems. Nutshell was most abundant (n=244), while sunflower and gourd seeds were also common. The subsistence remains identified from general recovery contexts is biased toward larger fruits, with the smaller chenopodium and maygrass seeds not as well represented. The high numbers of nutshell is surprising, but it may represent a high-energy food source utilized by prehistoric cavers. However, these fragments may also have been transported by woodrats outside their original contexts of use or storage. Finally, gourd fragments may be related to various storage or collection activities carried out by prehistoric cavers, including storage of food or water and collection of mined minerals. All examples are thin-fleshed, and likely served as containers rather than as food sources. Faunal subsistence remains recovered from prehistoric contexts were extremely rare, limited to only a few examples of feathers, fur, hair, and mussel shell. One of the mussel shell fragments appears to have been used as an expedient scraper.

Human paleofeces (n=255; 690 grams) were recovered from 14 of the test units. While detailed analyses of the contents and chemical residues was not attempted, qualitative observations indicated that they are highly fragmentary, and almost all contain chenopod and sunflower seed fragments. This suggests that the chenopod and sunflower seeds from general excavation samples may derive from fragments of human paleofeces rather than representing food caches or in situ use of food resources.

Density by volume of various material classes provided additional insights into differential spatial distribution of these materials and to potential identification of activity areas within the cave. The distribution of densities of torch debris and gypsum crystals (Figure 3) showed little overall correspondence. From this we infer that mining activity alone does not account for accumulation of torch debris in specific areas within the cave. Similar findings were derived from surface observations made by Hadley (2006) for the portion of the Main Cave passage in-cave from the Cataracts. Figure 3 also shows a general decrease in the density of both material classes with increasing distance from the entrance. However, distinct spikes in torch debris that do not correspond with spikes in gypsum density also suggest that specific portions of the cave were the focus of other prehistoric activities that required light and resulted in accumulation of torch debris.

Other activities that might be represented include subsistence storage and consumption, or consumption of cathartic salts. The distribution of subsistence remains among test units does not strongly correspond with the distribution of gourd remains (Figure 4), which suggests that the gourd was not used for food storage.

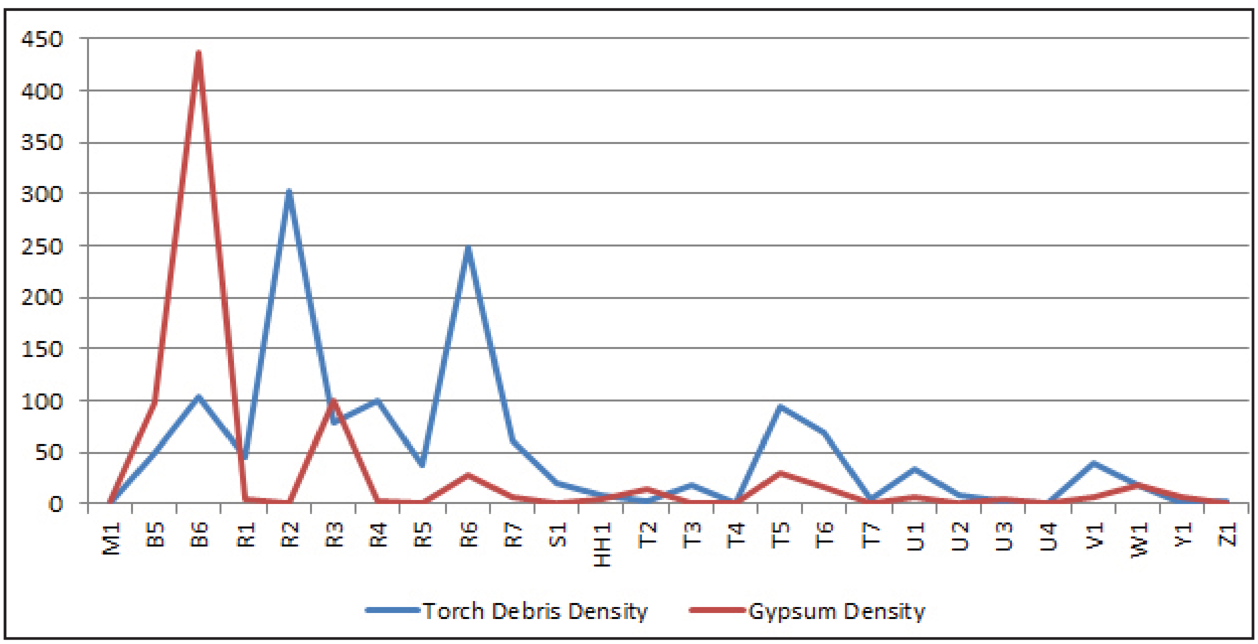

Figure 3: Density Data for Gypsum and Torch Debris from Stratum IIA Contexts for Selected Test Units in the Main Cave Section. Unit K1 has been omitted due to anomalously high gypsum density. Density values (y axis) are in grams per cubic foot, and test units are ordered in-cave from left to right.

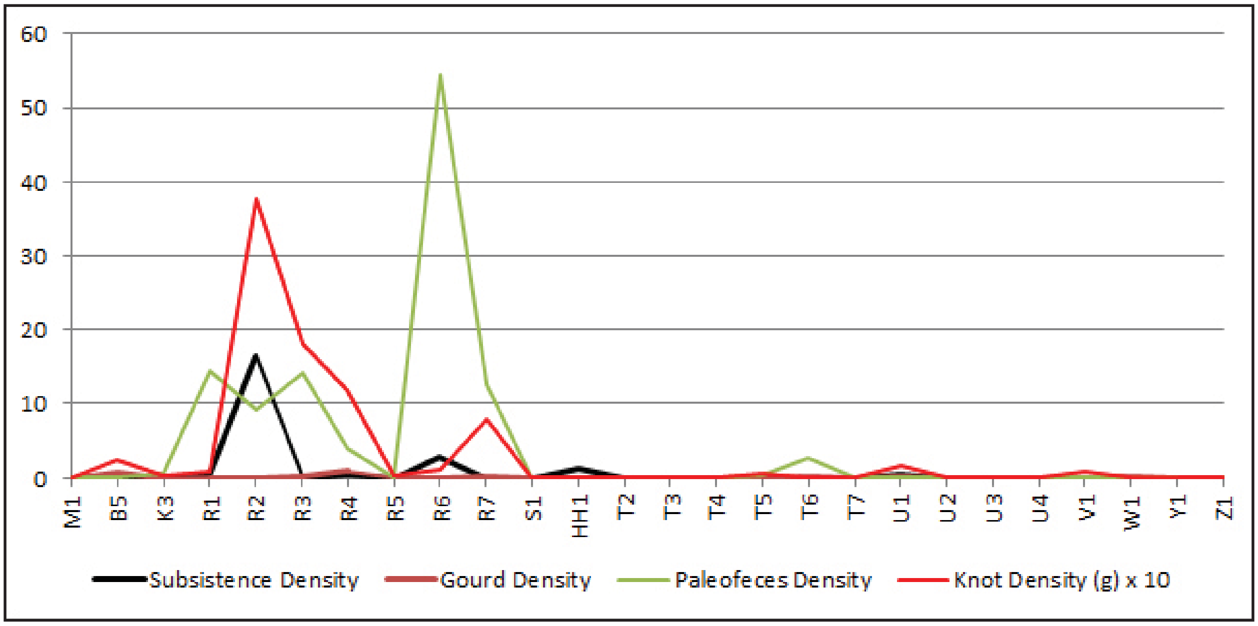

Figure 4: Density Data for Subsistence Remains, Gourd Fragments, Human Paleofeces, and Knots (x 10) from Stratum IIA Contexts for Test Units in the Main Cave Section. Density values (y axis) are in grams per cubic foot, and test units are ordered in-cave from left to right.

This figure also shows that paleofeces are most common in the R series of units, which were placed within and just in-cave from the Snow Room. This is a section of the cave where mirabilite and epsomite readily form on cave surfaces, and the high paleofeces densities suggest consumption of these salts took place in this area. Paleofeces are also generally in correspondence with the distribution of subsistence remains, which supports the earlier suggestion that some of the subsistence remains are derived from fragmented paleofecal material. However, there is no strong correspondence between the distribution of paleofeces and the density of torch debris. This lack of correspondence is understandable because consumption of these cathartic salts did not necessarily require illumination. Finally, though gourd density did not correspond strongly with density distribution of other subsistence remains, it is very strongly covariant with the density of gypsum crystals (not illustrated). This supports the interpretation that the thin-fleshed gourd fragments recovered from Mammoth Cave are primarily fragments of containers used for collection and storage of mined minerals.

These distributional data are not exhaustive and are not quantitatively rigorous, but they do indicate two broad patterns that are useful for making management recommendations for the proposed Trail Rehabilitation project. First, there is abundant evidence of prehistoric mineral mining along the Main Cave passage. This activity has resulted in accumulation of abundant prehistoric torch debris, gypsum crystals, torch ties, and gourd container fragments, all of which appear to be directly related to prehistoric mineral mining. The density of most of these material classes generally decreases with depth into the cave, but density of torch debris is also highly variable along the passage. Second, artifacts and material remains were recovered that indicate other activities were conducted besides mineral mining and simple illumination of passages. Subsistence remains, paleofecal remains, and knots/cordage all show highly variable distributions along the Main Cave passage, and also show strong concentrations in specific locations, including Giants Coffin (B Units) Snow Room (R units), Chief City (T and U units), and selected, localized concentrations at individual test units (such as V1). These locations therefore have great potential for contributing additional information about specific activities that were conducted within this cave system at particular locations.

Specific prehistoric activities were likely conducted in specific locations because particular cave resources were present in these areas or accessible nearby. This is obviously the case with the mining activities, which were conducted where minerals form on walls or in soft sediment deposits or precipitate on walls and ledges. Consumption of the cathartic salts also appears to have taken place near their source locations, such as the Snow Room.

However, locations where other activities were conducted may have little to do with mineral mining, or may correspond only partially to the mining activities. Access to water would be a necessity. Water is available in only limited locations in the upper-level passages, and is more abundant in the lower-level Historic Tour. One definitive finding of this project, is that these lower-level passages were used prehistorically, contemporaneously with the Early Woodland mineral mining activities carried out in the upper-level passages.

The architecture of the cave itself may have promoted more intensive use of some locations. Areas where multiple passages converge are junctions that provide access to other passages besides the Main Cave tour routes. The Giants Coffin area, for example, may have served as a staging area for sorties into smaller side passages, and this may account for a concentration of subsistence remains and other artifacts in the Giants Coffin area (B units). Wrights Rotunda is also a major passage junction, and surface inspection in other studies has shown abundant evidence of artifacts away from the current trail.

Recommendations

The density data, distributional data, and contextual information documented through these excavations form the basis for management recommendations for the Trail Rehabilitation project. A set of nine criteria was used to assess the contextual integrity, location, quantity and types of materials recovered at each test unit location. These data were combined with the initial walk-through observations to evaluated trail segments for their research potential. Maps were produced that showed cave reaches with nil, low, medium, and high research potential. Figure 5 shows the map produced for the southern half of the Lantern Tour Trail, with areas of archaeological research potential indicated by color codes. Similar maps were produced for the Historic Tour Trail and the northern half of the Lantern Tour Trail. These maps are the initial basis for recommendations regarding the type and intensity of additional archaeological work that may be required when rehabilitation construction is undertaken. No additional archaeological work is recommended in areas that have been evaluated as having nil archaeological research potential. Monitoring of construction activities is recommended for areas with low potential, and both monitoring and additional test unit excavations are recommended for areas with medium or high archaeological research potential. The specific level of work that will be required will depend on the type of construction activities that are undertaken, and the specific number and locations of additional excavations will depend on highly localized conditions, especially the integrity and depth of intact deposits below the existing trail. The work reported here will hopefully provide helpful guidance to the park personnel that manage resources and attempt to

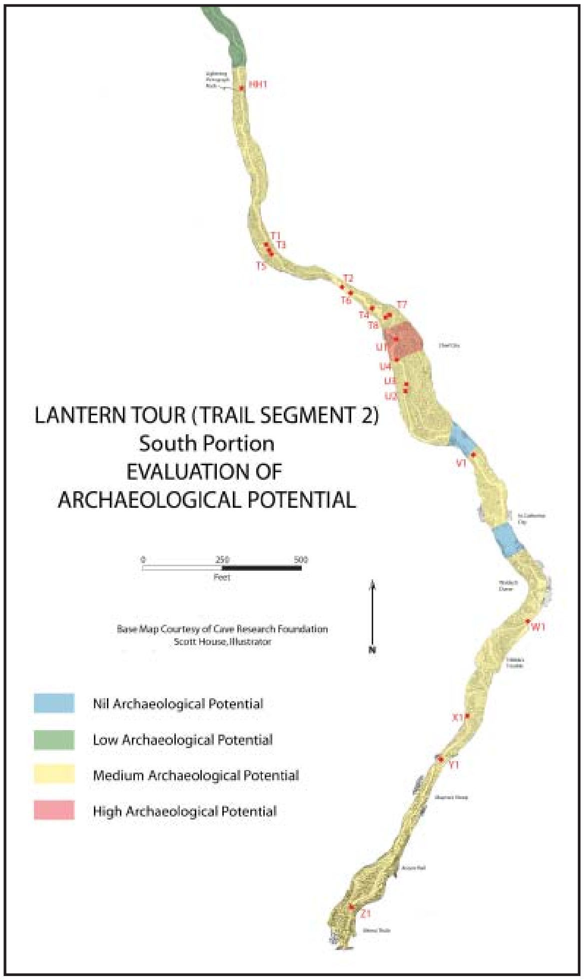

Figure 5: Archaeological Potential on the Southern Part of the Lantern Tour Route (Trail Segment 2)

balance the needs of the public, the goal of preserving scientifically significant cultural resources, and the mandate to preserve the natural resources of the park itself.

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Restoring the Kämper Map for the 21st Century: A Digital Approach

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Abstract

One would be hard-pressed to find any 20th Century spelunker familiar with Kentucky's Mammoth Cave system who did not also have some passing familiarity with the Kämper Map. The work of German engineer Max Kämper, who explored extensive areas of Mammoth Cave in the company of guide Ed Bishop in 1907-1908, the meticulous hand-drawn cave map would for decades prove the most reliable tool for navigating the miles of darkness – its tangled lines of ink the equivalent of Theseus' ball of twine in this natural labyrinth.

This effort had its inception in conversations between the author, who as the Visual Information Specialist for Mammoth Cave National Park frequently received requests for representations of the Kämper Map, and the Park's Curator, who found that frequent demand for access to the original was becoming detrimental to the object. At the same time, the Park Ecologist had immediate need of a digital version of the Map for several scholarly purposes, so the author undertook, initially, to simply acquire a detailed scan of the original to provide ready access for research and publications and decrease exposure of the original. The author's initial inspection of the Map, however, revealed conditions that propelled an expansion of methods to achieve the same set of goals. This paper is an exposition of the methodology employed in this restoration; findings and document analysis will be reviewed in a subsequent paper.

Initial Condition Assessment

The Kämper Map was drawn initially in graphite pencil, and then finished in colored inks on a heavy white paper sheet, approximately 1,326mm wide x 792mm high. No records exist documenting the previous conservation treatment(s?) of this unique object, which included application of a stabilization backing made of linen, followed by lamination, sometime prior to October 1995. At the time of this assessment, the map showed evidence of general fading, wear, and excessive handling. The paper has taken on a patina due to age and its original acid content. Some foxing and original erasure smudging is evident, along with accumulated pre-lamination soiling. There is no evidence of pre-lamination conservation cleaning. Tears and missing fragments mark the edges of the Map itself from pre-lamination handling, and breaks have begun to appear in the lamination itself. The periphery of the object has begun to exhibit a degree of rigid bowing that presents concerns should attempts be made to flatten it. The map colors exhibit fading in various degrees, with the originally green ink suffering the greatest loss of fidelity, in some areas to the point of near-complete loss of visibility.

Theoretical Basis and Rationale for a Digital Restoration

The standards for treatment of objects in National Park Service museums and archives are defined in the NPS *Management Policies 2006*, Chapter 5, and expounded upon in the NPS *Museum Handbook Part I*, and take a forward-looking approach to determining what path to take in managing an object such as the Kämper Map for the future. An item in a museum collection will be preserved in its present condition or stabilized if preventive measures are insufficient to reduce deterioration to a tolerable level, and Active conservation treatment (intervention) will be minimized to reduce the possibility of compromising the item's integrity. Restoration is permitted if restoration will not modify that item's known original character and will be accomplished using the techniques and materials that least modify the item and so that the materials can be removed at a later time (US DOI 2006a).

Particularly applicable to the Kämper Map is this standard of minimal action, a cornerstone in all conservation practice:

> *One objective of any treatment is minimal intervention to reduce the possibility of compromising the item's integrity. Often, efforts to repair, stabilize, and restore objects have been detrimental to the long-term preservation of objects. Earlier techniques may have altered or destroyed important features of objects. In some cases, no treatment might have been a better choice. In part, this is why the preventive conservation approach has developed over the last few decades (US DOI 2006b).*

Regrettably, the decision to laminate the Kämper Map may fall into the above description, and certainly complicates all questions regarding its care moving forward; lamination is no longer considered an acceptable conservation practice. Although some types of lamination may be reversible, object-specific factors may still render our most modern techniques inadequate to reverse past decisions.

> *Delamination is a complicated process that requires a trained paper conservator working in a suitable laboratory stocked with specialized equipment and chemicals. [. . .] Soluble media, such as the aniline inks and dyes used in some fountain pens, copying pencils, and even ruled paper, may dissolve when exposed to the solvents used for delamination. The process may also increase the fragility of documents on poor quality papers, such as the high-lignin wood pulp papers that became common after 1850. If the objects to be delaminated are in particularly bad shape, they may need additional conservation treatments. Once delaminated, objects will need to be rehoused, which could result in a need for expanded storage space (Munson).*

Given its particular characteristics, the Kämper Map would seem to be a problematic candidate for physical restoration under the current state of the art. Yet it appears evident that something must be done, as elements of the original map data threaten to vanish of their own accord, and the increasing fragility of the object must be balanced against the mandates to provide research access imposed by regulation (US DOI 2006c).

As an active tool for cave research, the Kämper Map has had remarkable longevity, and remains relevant for many purposes; demand to review it is likely to continue beyond the point that would be curatorially prudent. Some alternative means of satisfying research needs must be found that does not compromise the object's integrity. Moreover, some thought must be given to the possibility, however remote, of the entire loss of the object to fire or other disaster.

The Kämper Map presents an opportunity for digital, or virtual, restoration. Traditional conservation methods applied to historic maps and similar ephemera would be problematic in this case. The difficulties and risks inherent in physical conservation of a unique original, the extended possibilities for visual restoration and data discovery using digital methods, and the benefit of providing a means to limit exposure of the Map while still complying with 5.3.5.5.6 of the NPS Management Policies all argue for a virtual approach to the restoration effort for the Kämper Map, and that is the direction taken by this effort.

Methodology

Definitions

"Programmatic" herein refers to methods and techniques involving the use of computer programs and programming to digitally manipulate images and aspects of image data. Programmatic methods imply computational processes that effect change to an image on a mathematical or logical basis, as distinct from manual methods that rely upon the restorer's judgment.

"Layer" in the context of the Map refers to the discrete color separations Max Kämper applied in the creation of the Map; the use of the term is procedurally related to the creation of discrete data layers in the restoration.

Equipment Used

Test Scans: HP ScanJet 3760

Data Collection: Konica-Minolta Bizhub C350 Digital Duplicator in scan mode

Image Manipulation: Adobe Photoshop CS 5.5 on a Windows 7 64-bit platform.

Raw Data Scan

Test scans were made using the HP ScanJet 3760 at resolutions of 600ppi x 600ppi and 1200ppi x 1200ppi. Comparison between the resulting scans suggested that scanning the entire map at the higher resolution would not produce a significant benefit in information gained versus the cost in file size. Therefore, in the interest of data manageability, the restoration resolution was set at 600ppi x 600ppi.

The Kämper Map was scanned in RGB color mode in 279mm x 431mm sections with approximately 50mm overlaps for sectional registration. These scans were saved as native Adobe Photoshop (PSD) documents with a file size of approximately 200MB each. Copies were then made, and second copies made in JPG format for rough positioning purposes. The original scans remained untouched after being copied in order to preserve the initial data collection.

The raw scan copies were then manually overlaid and assembled into left and right halves of the whole map; assembly as a whole map at this stage would have resulted in an image file of an unmanageably large 3GB. Each half was then divided into a grid of subsections 7.5in wide x 8.0in high to create map sections of a manageable file size for practical manipulation, as multiple layers would be required during processing. As this grid incorporated no overlap, precise numerical positioning along the grid was critical.

Assembly of the raw scan data into a single two-dimensional representation for sub-sectioning revealed a certain number of positioning anomalies. These were anticipated due to the slightly warped areas in the fabric of the original, and no attempt was made to compensate for them; rather, they were left as visible anomalies to be rectified against raw scan data from alternate source scans. A single-pass, full-map scan to be completed by Clemson University in January 2013 should provide an additional baseline for accuracy.

Image Processing

Each subsection underwent identical initial processing to ensure a uniform baseline for individual restoration. The initial processing included the following:

- Creation of transparent, white, and black underlayers;
- Creation of empty layers for each

map color;

- Duplication of the original map data layer to create Layer1;
- On Layer1: Application of an Unsharp Mask: 300%, Radius 5px, Threshold 1px;
- On Layer1: Application of Posterize Adjustment: 12 levels;
- Duplication of Layer1 to create Layer2;
- Change of Layer2's Layer Mode to "Color Burn";
- Duplication of Layer2 to create Layer3;
- Ctrl-Select Layer1, Layer2 and Layer3, and Merge Layers.

This produced an enhanced visual data layer that could be either copied and pasted into target layers or left visible as an under-layer for individual color manipulation.

Note, however, that the use of "Color Burn" tends to over-darken areas where color is already more robust, leading to spots of dark brown or black that complicated programmatic differentiation using Color Range Selection. Subsequent trials substituting the "Multiply" Layer Mode for "Color Burn" rendered results slightly less vibrant but more homogenous, and in general more acceptable for processing; the latter sometimes proved more effective in isolating more delicate hues (Figure 1).

Where elements were nearly completely obliterated, useful results could sometimes be obtained using temporary nondestructive adjustment layers such as "Selective Color" to manipulate individual spectra (Figure 2). Referencing isolated image channels also occasionally revealed clarifying detail (Figure 3).

Establishment of Target Restoration Colors

One primary motivator for restoration of the Kämper Map is the fading of its original colors. Kämper keyed his map in five colors - brown, black, red, green, and blue - to designate five discrete layers of cave formation. Of these five colors, the green elements have faded most. The blue and brown elements have also deteriorated. The black and red elements have remained truest, but even these exhibit variable degrees of fading.

In order to establish a set of restoration colors matching Kämper's originals as closely as possible, histogram analysis and pixel sample averaging was conducted on select Map samples. A known color baseline was needed in order to calibrate the analysis. This restoration analysis assumed that Kämper chose a base white paper for his work, and therefore

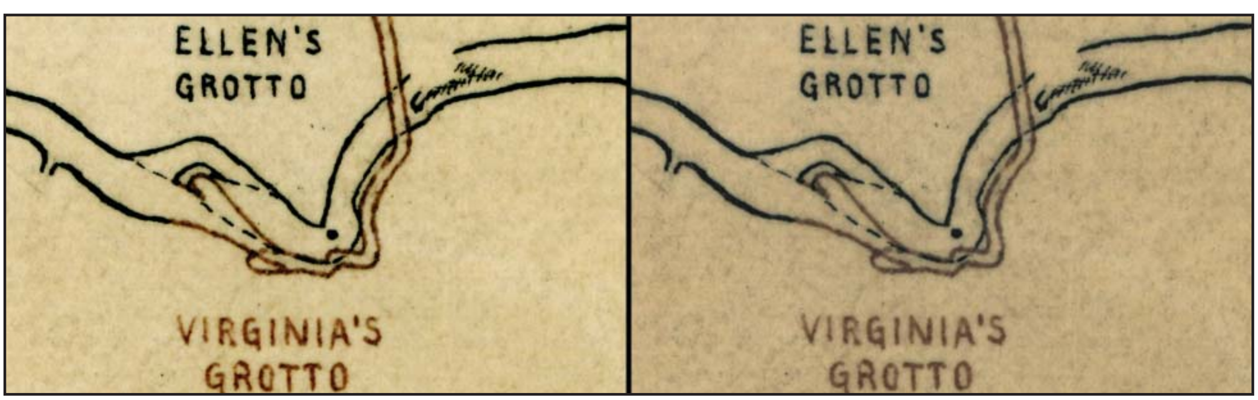

Figure 1: Left: Results of the "Color Burn" layer mode. Right: Results of the "Multiply" layer mode.

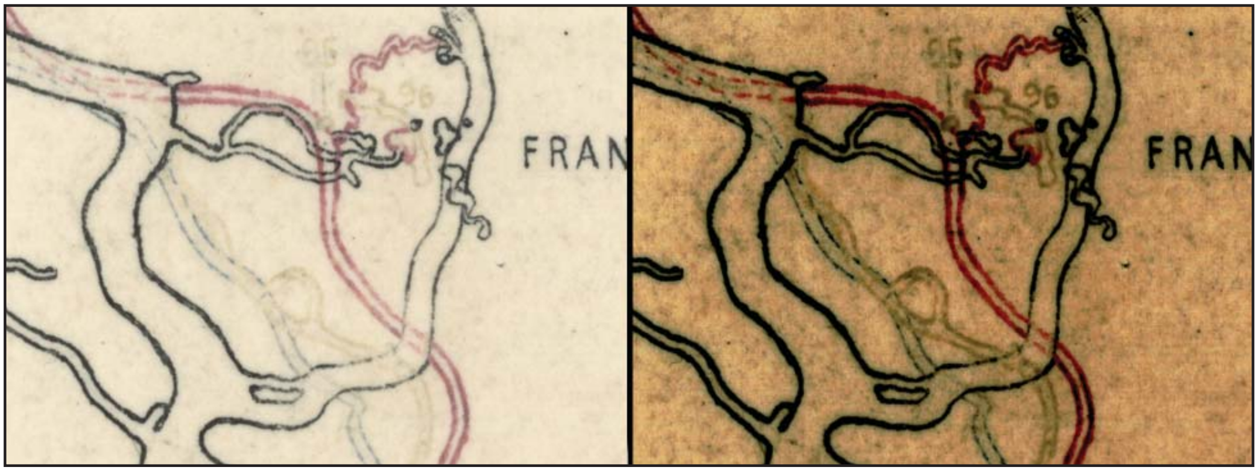

Figure 2: Left: Map sample showing multiple ink colors in close proximity. Note the deteriorated condition of the Green Layer (raw scan). Right: "Selective Color" filter applied to isolate and enhance the Green Layer.

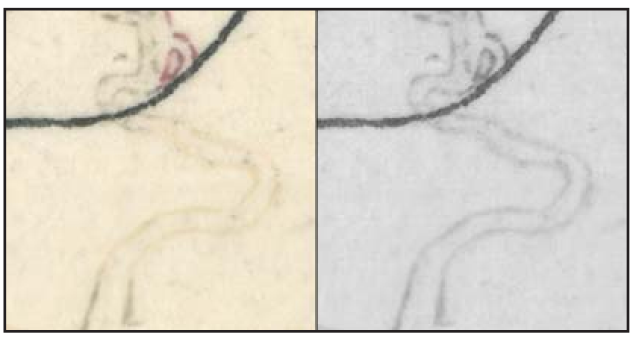

Figure 3: Left: Map sample for single-channel enhancement (raw scan). Right: Blue channel only. In this channel, the Green Layer feature can be more readily discerned and modified.

white could be used as the known color baseline for histogrammatic comparison/ conversion.

Taking representative 50mm x 50mm sections containing all five pigment colors, each section was subjected to [image adjustment] that resampled the paper matrix's patina-colored values as white, which simultaneously calibrated the color values to their corresponding calibrated values. To arrive at a single representative pigment for each color, five samples were taken of each color, from lightest to darkest, and the red, green, and blue (RGB) component values were individually averaged and then recombined to produce the target color.

This technique does not accommodate the variability in rates of aging between different pigments, and therefore should not be regarded as a true-color representation of Kämper's originals; rather, it should be thought of as a "close-color" solution that brings a level of accuracy to the restoration.

Combined Approach

Satisfactory results in restoring the Black and Red Layers could be achieved across the majority of the Map by the use of Programmatic techniques alone, but returning the Green Layer and significant sections of the Blue and Brown Layers to an equivalent vibrance would require human discretion – the eye would have to discern, the mind judge, and the hand implement, what the scanner and processor could not definitively separate. Moreover, the Programmatic reductions, while efficient in isolating colors, made no allowance for the aesthetic, and tended to result in jagged, pixelated lines unrepresentative of

Kämper's fine work. Therefore, at certain points, the restoration must necessarily venture beyond the representation of Kämper's handiwork to the representation of Kämper's intent, as represented in examples of the Overpainting (Not to be confused with Photoshop's "Underpainting" filter.) and Manual methods. This is a heavy responsibility, and every instance of such extrapolation was built upon an evidentiary premise drawn from the work itself. (Figure 4)

A case in point is Kämper's letterforms. Although Kämper used ruling lines in pencil to ensure consistency in his lettering, close examination shows that the letters have not survived well as a class of objects, with a tendency to deteriorate at the ends of ascenders and descenders, and where parts of certain letter bodies are thinner. In numerous cases large parts of some letters are missing, and in some instances entire words are almost illegible, particularly in the Green Layer. Programmatic reconstruction proved unsatisfactory, and a decision was ultimately taken to reconstruct Kämper's letterforms by digital stylus, using the Paintbrush tool on a brush setting of 6px width (based on an averaged sampling of letterform measurements) and a hardness of 90. For smaller placenames, a 5px width was used. Kämper's actual letterform was traced as closely as possible; if not possible, a letter would be created matching the stylistic character observed in Kämper's hand for other instances of that letter (Figure 5).

A Note on Aesthetic Responsibility

While theories governing the restoration of historic fabrics emphasize the importance of distinguishing between authentic materials and the work of restoration, the "historic fabric" in this case remains, in fact, unchanged. The result of this restoration effort is not an altered original, but a kind of meta-document, a framework not merely to protect and display the original, but to enhance and illuminate it in multiple ways, and to derive additional meaning. Recognizing the additive potential of these processes, the decision was made to create and preserve programmatic layers with the greatest possible fidelity to Kämper's original stroke work, but also to prepare a complete set

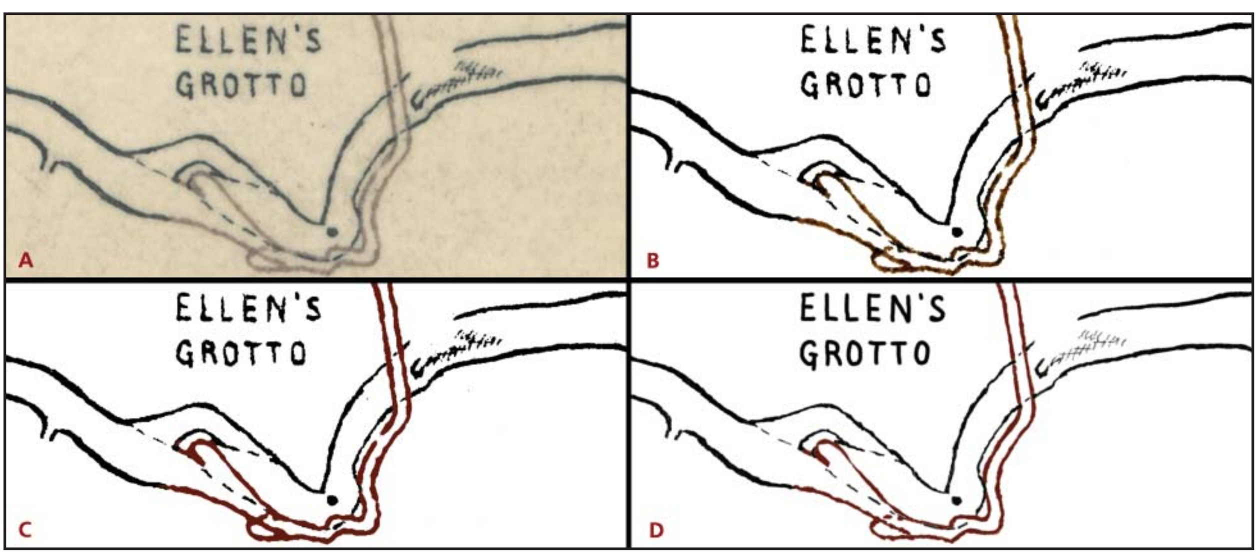

Figure 4: A: Unrestored "Ellen's Grotto" sample featuring Brown and Black Layers (raw scan). B: After Programmatic treatment. C: After Overpainting treatment. D: After Manual treatment.

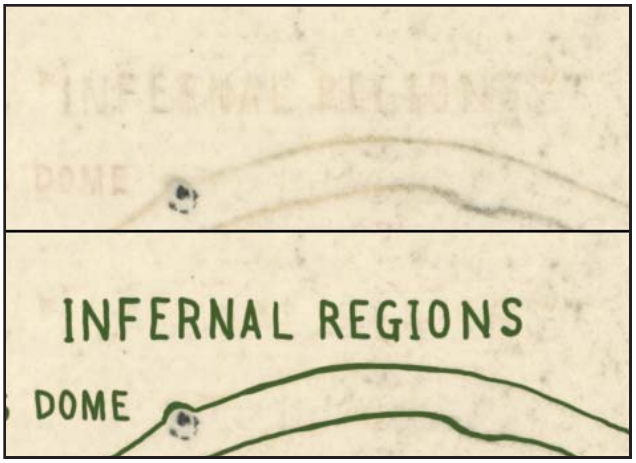

Figure 5: Top: Detail of "Infernal Regions", Green Layer (raw scan). Bottom: After Manual treatment.

of layers to augment to the programmatic enhancement, reconstructing Kämper's stroke work manually by stylus to restore ink homogeneity and robustness of line.

Recommendations for Future Research

Further information about the Kämper Map may be gleaned through imaging under ultraviolet, infrared and flourescent spectra, as well as x-ray radiography, which may reveal details of map construction or other features not evident under visible light.

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The Mammoth Cave Mushroom Company: A Brief History of a Short-Lived Venture

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Abstract

The Mammoth Cave Mushroom Company was formed in August 1881 during a particularly contentious period of family struggle for control of the cave, its resources, and tourism operations. This paper documents the history of the company from original company records and family letters. It places the Mammoth Cave operation within the larger historical context of mushroom production in caves as possibly the first such operation in the United States. It traces developments at the cave during the fall of 1881 as Anthony Muzarelli oversaw preparation of mushroom beds and supporting infrastructure and identifies sources of tension between the new mushroom business and the long-standing tourism operation. Finally, it offers a hypothesis about who sabotaged the mushroom beds with coal oil in December 1881, leading to the demise of the company before it had produced a single fungus.

Sable Melodists

Janet Bass Smith[1]

[1] Interpretation, Mammoth Cave National Park

Abstract
Inside Mammoth Cave on Broadway Avenue, between the last TB hut and Star Chamber, the name Sable Melodists is inscribed on the wall, using what appears to be charcoal. Next to Sable Melodists are the names of two men: R. H. Condon, and J. M. Foans. (See Figures 1, 2, and 3) When the name Sable Melodists was researched several years ago, the only information available was that it was a minstrel group. A recent search revealed more information, and provoked a more complete investigation of minstrel groups and minstrel shows, and their evolution.

Introduction
Minstrel shows developed in the 1840s, peaked after the Civil War, and remained popular into the mid 1900s. They evolved from two types of entertainment popular in America before 1830 – the impersonation of blacks given by white actors between acts of plays or during circuses, and the performances of black musicians who sang, with banjo accompaniment, in city streets. Minstrelsy was a product of its time, the only entertainment form born out of blind bigotry. In these shows, white men blackened their faces with burnt cork to lampoon Negroes, performing songs and skits that sentimentalized the nightmare of slave life on Southern plantations. Blacks were shown as naive buffoons who sang and danced the days away, gobbling "chitlins," stealing the occasional watermelon, and expressing their inexplicable love for "ol' massuh." "Blackface" and "minstrelsy" are not true synonyms. Blackface performers were around several decades before the first minstrel shows evolved. "America was crazy for blackface. To the twanging thwang of the banjo, and the clatter of tambo and bones – tambourine and bone castanets – white men smeared burnt cork on their faces to sing, waggle their legs in imitation of blacks dancing, and tell jokes in "negro" dialect. Between 1750 and 1843, over 5,000 theater and circus productions included blackface." (Carlyou 2001)

Figure 1: Entire Sable Melodist inscription (photo by Charles J. DeCroix)

According to T*he Encyclopedia of New York City* blackface acts were common features in circuses and traveling shows from the 1790s onwards (Jackson 1995). All this moved to a new level in the 1820s when white entertainer Thomas "Daddy" Rice, who, between 1828 and 1831, developed a song-and-dance routine in which he impersonated an old, crippled black slave, dubbed Jim Crow. He painted his face with burnt cork and performed the song *Jump Jim Crow* on stage. He first heard it from

Figure 2: Sable Melodist part of inscription only (photo by Charles J. DeCroix)

Figure 3: Names only, R. H. Condon J. M. Foans (photo by Charles J. DeCroix)

an old black street singer who supposedly made up the lyric about his own name:

> *First on de heel tap,*
> *Den on the toe*
> *Every time I wheel about*
> *I jump Jim Crow.*
> *Wheel about and turn about*
> *En do j's so.*
> *And every time I wheel about,*
> *I jump Jim Crow.*
>
> *– From 1823 sheet music*

This routine achieved immediate popularity, and throughout the 1830s Rice had many imitators. "Jim Crow" turned out to be more than a popular song. It became the name of one of minstrelsy's stock comedy characters, and, later, a by-word for legalized racial oppression.

> *In 1828, Jim Crow was born. He began his strange career as a minstrel caricature of a black man created by a white man, Thomas "Daddy" Rice, to amuse white audiences. By the 1880s, Jim Crow had become synonymous with a complex system of racial laws and customs in the South that enabled white social, legal and political domination of blacks. Blacks were segregated, deprived of their right to vote, and subjected to verbal abuse, discrimination, and violence without redress in the courts or support by the white community." (Wormser 2003)*

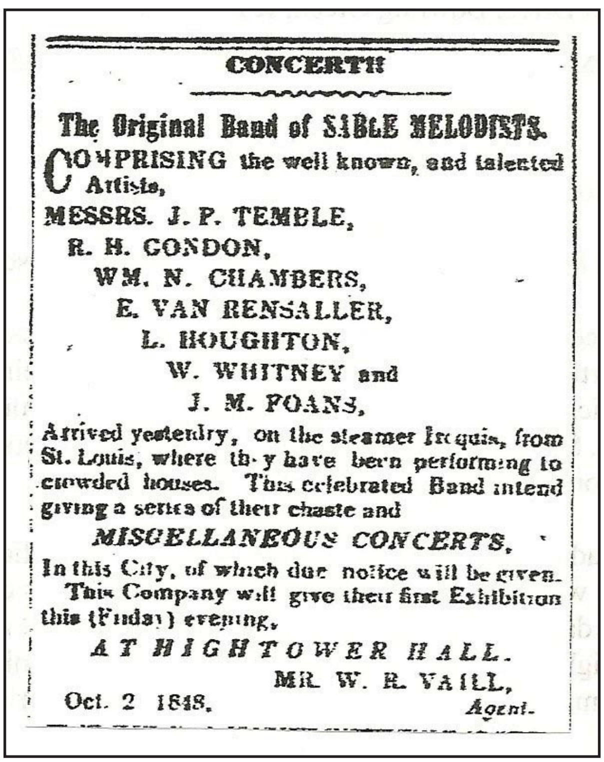
The Sable Melodists was a typical minstrel group of white performers, appearing in blackface and performing African American songs, satirizing Negros, portraying them as good-natured ignorant buffoons. A group with that name is advertised in the *Memphis Appeal* on November 3, 1848 (*Memphis Appeal* 1848). (Figure 4) The ad states that the "original band" of the Sable Melodists was to present a concert in Memphis on "this Friday evening." The date at the bottom of the ad is Oct. 3, 1848. In an email the date discrepancy was explained by the librarian at the University of Memphis Libraries as follows:

> *Printing errors in newspapers were not uncommon back then and is probably the best explanation I can give for the discrepancy. I would go with the date of the newspaper rather than the date in the ad since the local editor wrote about the group performing in Memphis in a subsequent paper. I suspect what happened is that the printers*

were using an old ad from another city and changed everything relevant except the date (per comm McKibben 2010).

The names of the members of the group listed in the ad are J. P. Temble, R. H. Condon, Wm. N. Chambers, E. Van Rensaller, L. Houghton, W. Whitney, and J. M. Foans. Two of these names are the same names that appear with the Sable Melodists signature inside the cave (R. H. Condon, and J. M. Foans). Therefore, we can assume that this group (or at least these two members of the group) visited Mammoth Cave.

No information seems to exist regarding their visit to Mammoth Cave. It's not clear if only two of the group visited or if the entire group visited, if they performed at the hotel or in the cave. It is unlikely that even if the entire group visited Mammoth Cave, they would have performed a complete show inside the cave, although they might have sung a few songs. They might have performed at the hotel. In the visitors' accounts from that period that we have on file, none mentions a performance by a minstrel group. The date they were at Mammoth Cave is also not available, but certain events seem to suggest that it was sometime in 1848 or 1849. The ad in the Memphis paper says they arrived by the steamer from St. Louis where they had been "performing to crowded houses" (Memphis Appeal 1848). It's possible that they came to Mammoth Cave either just before or after the Memphis performances.



CONCERT!!

The Original Band of SABLE MELODISTS.

COMPRISING the well known, and talented Artists,

MESSRS. J. P. TEMBLE,
R. H. CONDON,
WM. N. CHAMBERS,
E. VAN RENSALLER,
L. HOUGHTON,
W. WHITNEY and
J. M. FOANS,

Arrived yesterday, on the steamer Iroquois, from St. Louis, where they have been performing to crowded houses. This celebrated Band intend giving a series of their chaste and

MISCELLANEOUS CONCERTS,

In this City, of which due notice will be given.

This Company will give their first Exhibition this (Friday) evening,

AT HIGHTOWER HALL.

MR. W. R. VAILL,
Oct. 2 1848. Agent.

Figure 4: Ad appearing in Memphis Appeal, Nov. 3, 1848, and Nov. 7, 1848

The signatures inside the cave appear to have been inscribed using some kind of charcoal. Burnt cork was part of their costumes, so it's possible that they might have carried pieces of burnt cork with them into the cave, and used that to write on the wall. In an experiment at my home, writing that looks very much like that inside the cave was produced by using a cork from a wine bottle, burning the end, and writing on a rock.

If the Sable Melodists had performed at the hotel during their visit to the cave, they would probably have performed a variety of music, typical of minstrel groups of that time, including songs that had racial overtones and were sung in black dialect. Many of these songs were learned by white men who spent time with slaves, and then performed their songs. The repertoire also included songs by Stephen Foster who was writing songs for The Christy Minstrels, a famous minstrel group of the late 1840s. The program might also have included songs that were typical popular ballads of that era. The song, *Emma Dale*, published in 1850, was performed by the Sable Melodists, and is of the latter type. The lyricist, W. N. Chambers, and the composer, J. P. Temble, are listed in the Memphis newspaper ad as members of the Sable Melodists.

According to an account of a visit to the cave in 1849 by a visitor from Scotland, John Wilson (Thomas 2010), his guide was Stephen Bishop. (Figure 5) Stephen was an African-American slave, owned by Dr. Crohan who also owned the cave. He was well respected as a guide, and was also considered a great caver and cave explorer. According to John Wilson, twice during their visit Stephen and the other guides sang the songs *'Ol Uncle Ned*, and *Oh, Susanna (Susana).* The first time was between Star Chamber and the Cataracts:

> *While we were resting here Stephen sang some negro songs very well too—a merry fellow is Stephen, and has a good voice. One of his ditties pleased us very much—it was about uncle Ned, an old nigger, who died long ago, and who had no wool on de top ob his head, de place where de wool ought to grow (Thomas 2010).*

On another day at Echo River he wrote:

> *At length the glimmer of the lamps is seen in the distant darkness, and the guides approach us, awakening the echoes with "Oh Susanna," "Old Uncle Ned," and other negro ditties (Thomas 2010).*

Figure 5: Engraving by N. Dmitrieff of Stephen Bishop, guide. Published in Scribner's Public Magazine, October, 1880

Both of these songs were written by Stephen Foster for the Christy Minstrels, are in Negro dialect, and use the word "nigga" or "nigger" that would now be considered offensive. Assuming that Stephen learned these songs from the Sable Melodists, which is a real possibility, then the Sable Melodists probably visited Mammoth Cave in either 1848 or 1849. (Words for the song *Old Uncle Ned* are at the end of this paper.)

When one looks at the words of this Stephen Foster song, the first reaction is surprise that Stephen Bishop and the other guides would sing songs which contain the word "nigger." However, in *Old Uncle Ned* the word is not "nigger," but "nigga." According to a website defining "nigger" (www.answers.com/topic/nigger, August, 2010), in today's culture the word "nigga" is a common term used by the black culture to refer to any male of any race or ethnicity, and is sometimes used to refer to any person, male or female. The point is made that the use of the word by African Americans is acceptable, but its use by white people is not. However, this usage probably cannot be applied to the slave culture of the 1800s. Many sources state that by the 1800s, the word "nigger" was offensive, and sensitive people had begun substituting "black" to refer to people of color. So why would Stephen and the other slave guides sing songs using that word? Perhaps they had learned these two Stephen Foster songs from the Sable Melodists during their visit to Mammoth Cave, and liked the sound of them. Perhaps the word wasn't as offensive to the slaves as it is to everyone now, or perhaps they sang them because they knew it was expected of them, and the white visitors liked the songs and would give them a tip. The fact remains that they did sing them, and we cannot possibly know their motivation or thinking at the time.

The history of minstrel shows indicates how white Americans have taken music of the African American culture and used it in their own music. Whether it is Stephen Foster's popular songs, jazz, blues, rock, hip-hop, or rap – all of these have their roots in the music of the black culture, and have become truly American music.

Following are the words of one of the songs that we know Stephen Bishop sang, and might also have been sung in Mammoth Cave by other slave guides.

Old Uncle Ned
By Stephen Foster, 1848

Dere was an old Nigga, dey call'd him uncle Ned –
He's dead long ago, long ago!
He had no wool on de top ob his head –
De place whar de wool ought to grow.

Den lay down de shubble and de hoe,
Hang up de fiddle and de bow:
No more hard work for poor Old Ned –
He's gone whar de good Niggas go,
No more hard work for poor Old Ned –
He's gone whar de good Niggas go.

His fingers were long like de cane in de brake,
He had no eyes for to see;
He had no teeth for to eat de corn cake,
So he had to let de corn cake be.

Den lay down de shubble and de hoe,
Hang up de fiddle and de bow:
No more hard work for poor Old Ned –
He's gone whar de good Niggas go,
No more hard work for poor Old Ned –
He's gone whar de good Niggas go.

When Old Ned die Massa take it mighty hard,
De tears run down like de rain;
Old Missus turn pale and she gets berry sad,
Cayse she nebber see Old Ned again.

Den lay down de shubble and de hoe,
Hang up de fiddle and de bow:
No more hard work for poor Old Ned –
He's gone whar de good Niggas go,
No more hard work for poor Old Ned –
He's gone whar de good Niggas go.

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Long Cave, Mammoth Cave National Park, Edmonson County, Kentucky

Stanley D. Sides[1], Norman Warnell[1]

[1] Cave Research Foundation

Abstract

The story of Long Cave, later to become Grand Avenue Cave, is thoroughly intertwined in the rich history of saltpeter production and the show cave industry of Central Kentucky. The cave's history parallels the early history of Mammoth Cave that is five miles away, the history of nearby Short Cave, and the development of Diamond Cave and Proctor Cave as show caves by the Proctor families. Today the cave is an important bat hibernaculum protected by the National Park Service. The cave is gated and locked, and entry is by research approval only.

A patent on the land that included Long Cave was taken shortly after Kentucky became a state in 1792. Mammoth Cave was known by 1797, and Pheltius Valentine Simons received a certificate of ownership of Mammoth Cave in 1798. Simons sold the property to his relative, John Flatt for the purpose of making saltpeter. Flatt's Cave was soon one of several caves under the name of McLean's Cave after John, Leonard and George McLean purchased the cave sometime before 1808. The McLeans sold Dixon Cave to Charles S. Morton on January 22, 1808. Sometime before 1810 the McLeans sold Flatt's Cave, soon named Mammoth Cave, to Fleming Gatewood and Charles Wilkins for the manufacture of saltpeter.

The McLeans bought other saltpeter caves including Long Cave and nearby Short Cave. Richard Richardson's 50 acres including Short Cave were surveyed for George and Leonard McLean on October 19, 1810. David Smith's 70-acre tract including Long Cave was surveyed for George, Leonard, and John McLean on the same date after it had been assigned to the McLeans on September 1, 1810. Saltpeter production began in Long Cave and nearby Short Cave. Jim Cave, to the north of Long Cave, was stripped of its sediment with the saltpeter likely produced at Long Cave's nearby furnaces. In August 1811 the mummy Fawn Hoof was discovered in Short Cave by the nitre diggers and displayed at Mammoth Cave, bringing fame to the cave.

Robert Montgomery Bird visited Mammoth Cave in 1833 and 1836, and was guided through the cave by Fleming Gatewood. In his 1838 book, "Peter Pilgrim or a Rambler's Recollections," Bird related a story that is the first printed mention of Long Cave as Wright's Cave (Pit Cave). Gatewood was to meet at the cave with Wright and another man who was a saltpeter miner to investigate Long Cave's use for saltpeter mining. Gatewood failed to arrive due to bad weather. Wright and the miner proceeded to explore the cave alone and ran out of candlelight. Wright fell down a pit and was killed. The other person crawled in the dark and finally reached the surface to spread the alarm for help. Gatewood and workmen from Mammoth Cave retrieved Wright's body in the published story. W. W. Wright's name is prominently seen on the wall today at the edge of the pit at Shaler's Dome, but he did not die in the cave in 1812. He was writing his name on the cave walls as late as 1853.

Saltpeter dirt was mined in the entrance passages of Long Cave, but apparently much of its deep sediment fill was not rich in nitrate. The McLeans sold Long Cave and Short Cave to John Hann of Lancaster, Kentucky on January 10, 1812. On April 20, 1818 Hann assigned the property, including both caves, to Jane and Elizabeth Wright, presumably the daughters of W. W. Wright. Jane Wright married Gelon Hann on October 13, 1829. She later married Thomas Proctor on March 8, 1835 after Gelon Hann's death. Following Elizabeth's death, her heirs sold one half of Long Cave to William Hopkins Woolsey in 1839. Jane Wright Proctor sold the other half to Eldridge Hopkins Woolsey in 1860. The Woolseys also owned Short Cave by 1860.

Eldridge Hopkins Woolsey conveyed the Long Cave property to his two sons Chester Porterfield Woolsey and Felix W. Woolsey. Felix conveyed his part to his brother Chester Porterfield. Nancy Woolsey conveyed that portion of the land she owned to W. W. Age. Age was an agent between the Woolseys and Proctors. Larkin J. Proctor had assisted Age, crippled by the Civil War, in getting a Civil War Pension. W. W. Age purchased the Long Cave property from the Woolseys and transferred it to George M. Proctor, his brother Larkin J. Proctor, and Larkin's spouse Mary E. Proctor for $700.00 on April 5, 1876.

George Proctor's name was on the deed for the Long Cave property but he was insolvent. Proctor was a landowner, had run Bell's Tavern with his second wife, Maria Gorin Bell Proctor, had commercialized Diamond Cave, and produced lithographic stone from a quarry in Glasgow Junction (Park City). Maria Proctor had died in 1865. Her uncle, Joseph Rogers Underwood, owned Diamond Cave from 1859 until he sold it to George Proctor's son, John Proctor, in 1866. John and his father continued to develop Diamond Cave as a show cave.

Larkin Proctor owned the stagecoach line from Three Forks or Glasgow Junction to Mammoth Cave. He ran Mammoth Cave from 1856-1861 and 1866-1871 for Joseph Rogers Underwood who was the Mammoth Cave Estate managing trustee. Thereafter he practiced law and farmed until becoming owner of Long Cave and Proctor Cave.

H. C. Briggs and Joseph Reynolds held George Proctor's promissory note, which he was unable to pay. The Edmonson County Court sold George Proctor's half to pay the debt he owed Briggs and Reynolds. Larkin and Mary paid their brother's note and became owners of Long Cave and land in September 1877. Larkin proceeded with opening Long Cave to the public as Grand Avenue Cave and brought the Salts Cave mummy to the cave. He simultaneously developed nearby Proctor Cave as a show cave. He was deeply involved in the development of the Mammoth Cave Railroad to serve his caves. John Proctor, his nephew, lost Diamond Cave from the Proctor family on April 21, 1879 to Seth B. Shackleford because of unpaid debts from land speculation. John Proctor moved on to a distinguished career in public service, becoming Kentucky's state geologist and a prominent federal civil servant.

Thomas E. Lee was a close friend of Larkin Proctor and assisted in Long Cave's commercial development as Grand Avenue Cave. He, with J. L. Lee and W. D. Cutliff, had discovered the mummy of an aboriginal male child in Salts Cave on Flint Ridge on March 8, 1875. Lee and his family lived in a house on the Grand Avenue property while managing the cave. He was a skilled carpenter that probably built the extensive ladders in Lee Avenue today named the "banzai ladders." The cave had a wooden door at the entrance leading down substantial wooden steps into Grand Avenue at the 1812 saltpeter hoppers. Just beyond Shaler's Dome in Echo Avenue the passage continued as Fairy Avenue. Larkin Proctor had a hut constructed in an alcove in Fairy Avenue where Little Al, the Salts Cave Mummy, was on display as having been found in Grand Avenue Cave. The book "Grand Avenue Cave," published in 1892 by T. O. Chisholm to promote the cave states, "In 1876, while Mr. Thomas E. Lee was making some explorations in an avenue which was subsequently named for him, and which has not yet been visited, he found lying on a ledge of rock in a deep chasm the remains of one of the human species. Closer examination revealed it to be the body of a young girl." The mummy was the prominent feature of a visit to the cave, much as Fawn Hoof, the Short Cave mummy, had been in Mammoth Cave sixty years earlier.

An article entitled "The New Wonderland," subtitled "A Kentucky Cave of Vast Extent Just Coming into Notice," was published in the Bismark Daily Tribune, November 25, 1891 and included a sketch map indicating miles of passages in Grand Avenue Cave. It states the mummy had been discovered in the cave 25 years earlier. The article declares the cave atmosphere preserved the mummy, and that fruits and vegetables were improved by storage in the cave. A Louisville Courier Journal article March 28, 1896 tells of J.B. Briggs of Russellville "and others" experimenting with storing "lemons, oranges, and other Florida fruit and eggs that were kept fresh for months." The same article tells how Col. R.H. Lacy "kept eggs in the cave for nearly a year." Tracks for a railed transport system were placed in the cave, but using the cave for storage was never successful. The tracks found today in nearby Martin Cave are probably the tracks that were once used in Long Cave.

Larkin and Mary Proctor lived at Long Cave promoting its commercialization as a show cave until later moving to Proctor Cave Hotel. A small railroad depot and platform terminated the short spur line to Grand Avenue Cave from the Mammoth Cave railroad at Chaumont. However, a railroad line to the cave, an Indian mummy, a book, and articles written on the cave were not enough for the cave to compete with nearby Mammoth Cave, Diamond Cave, Proctor Cave, Osceola Cave and soon, Colossal Cave. The arrival of the automobile at Mammoth Cave in 1904 signaled the expansion of self-directed tourism that was not confined by horseback, stagecoach or railroad. This led to the opening of many show caves in the area and competition for visitors that was named the "cave wars."

On September 1, 1884 Larkin and his wife conveyed the Proctor Cave tract of land to Robert Rodes because of an old debt of long standing. Several years earlier, the Proctors had obtained money from the Globe Building & Loan Company of Louisville, Kentucky, to build a hotel on the Proctor Cave tract and executed notes and mortgages on the same. A few years later, finding themselves "utterly unable to pay this mortgage," they deeded a one half interest in the tract to their grandson, James W. Proctor, if he would pay the note. James paid the note, but was never told that Rodes was also holding a note on the property.

Rodes informed Larkin that he could redeem the Proctor Cave tract by paying him $478.00 with 8% interest from September 1, 1884. Despite increasing problems with their health and the lack of commercial success of the caves, Larkin and Mary's interest in their caves never dwindled. In January 1885 Mary Proctor became sick with an abdominal abscess and was confined to her bed for three weeks. She died January 27, 1885 at age 69 years.

Following the death of his wife Mary, Larkin Proctor paid only $60.00 on the Proctor Cave debt and nothing more was ever paid. Finally the court, ruling in favor of Robert Rodes, ordered the land sold at public auction on September 13, 1888. Rodes became the owner. In a quick maneuver on May 1, 1891 Larkin Proctor and his second wife, Jennie Fernoy Proctor, sold the Grand Avenue Cave tract of land to R.H. Lacey of the L & N Railroad. Using the money from this sale, they redeemed the Proctor Cave tract from Rodes. In March 1894 Proctor surrendered all his interest and rights in the short railroad line to the platform and depot near Long Cave to Lacey, who was secretary of the Mammoth Cave Railroad. Larkin Proctor lived at his Proctor Cave Hotel until his death on November 19, 1895.

Lacey and his heirs did not attempt to redevelop Long Cave as a show cave, and its use for storage must have been short-lived. However, a famous aspect of Long Cave's history is stories that a hermit lived in the cave. In reality a cave explorer and digger of note, John D. Hackett of Tesnus, Texas, did spend time in the cave. On arrival in the cave region in 1917, Hackett boarded at the County Line House near Chaumont with E. M. Doyel. For a short period Hackett could not stay at the Doyel's house. Friends assisted him to move temporarily to Long Cave. The winter of 1917-1918 was one of the coldest on record. Hackett lived in the cave three months or less during the harsh winter, but was still exploring local caves and would walk daily to the Chaumont post office and store. His letters state he nearly froze to death on March 4, 1918 when it was 24 degrees below zero. Walking from the cave to the Chaumont post office he froze his left ankle, from which he never completely recovered.

After Larkin Proctor's death the Warren Deposit Bank demanded settlement of the Proctor Cave tract to redeem a note left unpaid by Larkin's widow. James Proctor then discovered, to his alarm, that he was about to lose Proctor Cave. He promptly took his step-grandmother to court, in an effort to reclaim his half interest in the property.

The Edmonson County court ordered the sale of Proctor Cave on April 3, 1899 at the courthouse in Brownsville to settle the claim that James Proctor held against the estate of Jennie F. Proctor. James Proctor became the purchaser of the half interest in the property for $143.50 in addition to paying the debt on the note to the Warren Deposit Bank. He soon sold this land and Proctor Cave to the Colossal Cavern Company of L&N Railroad on August 20, 1901 finally ending the Proctor families' interest in the caves of Joppa Ridge: Diamond Cave, Grand Avenue Cave, and Proctor Cave. L&N Railroad later donated Proctor Cave to Mammoth Cave National Park.

In March 1935, the United States District Court at Bowling Green filed condemnation proceedings against R. H. Lacey's estate to force sale of the Long Cave property. The deed of conveyance of the Long Cave property to the United States was entered April 1940 for the sum of $2,300.00. Long Cave thereafter became a valued part of Mammoth Cave National Park. Short Cave and Diamond Caverns remain private property outside the National Park.

Written as part of Stanley D. Sides' Mammoth Cave National Park research project, MACA H1, and Norman L. Warnell's research project, Mammoth Cave Communities.

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The Mammoth Eagle: The CCC Era at Mammoth Cave

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Abstract

Today's visitors to Mammoth Cave National Park sleep in cabins, drive over roads, and hike on miles of surface and cave trail constructed by the Civilian Conservation Corps (CCC) and others during the 1930s and 40s to create Mammoth Cave National Park. While this was without question a difficult transition for the residents and region, the work completed during this time is nothing short of monumental. Compiling information from archives, oral histories, and camp newspapers, as well as field observations, this presentation will shed light on several forgotten or misunderstood stories from this period in Mammoth Cave history. The creation of Mammoth Cave National Park also serves as an interesting case study regarding the rapid expansion of the National Park Service during this era and the competing interests between wilderness conservation and public access to recreation.

From 1933 through 1942 four CCC camps operated within the proposed national park. Kentucky NP-1 was not only the first CCC camp in Mammoth Cave, it was the first CCC camp in Kentucky – a point of pride mentioned by the superintendents whenever this camp was threatened with closure. Camp 1 housed Company 510, an African American Camp, on the Flint Ridge using property that was once a country club and later would be used as the Job Corps site. Camp 2 housed Company 543, with enrollees largely from Kentucky, on the Mammoth Cave Ridge near the New Entrance Motel. Camp 3 housed Company 582, men predominately from northern Ohio, on Joppa Ridge not far from Joppa Church. Lastly, Camp 4 housed Company 516, mostly from Indiana, north of the Green River where the Maple Springs group campground currently exists. There are some complications to this story as various companies were disbanded and camps closed or had other companies move to a new camp, however, these camp and company associations are largely true for the majority of this period. Initially, all four camps contributed to "Cave Man" a professional style newspaper with information relevant to the entire area. Later, this newspaper was separated into four, more amateur, newsletters. Camp 1 produced "The Mammoth Eagle," Camp 2 claimed the name "Cave Man" (over protests from Camp 3 who felt they had a more legitimate claim to the original paper), Camp 3 produced "Axe and Sledge," and Camp 4 had "Camp Cade Courier" (not to be confused with "Cades Cove Courier" from Great Smoky Mountains National Park!). These newsletters include information about social and sporting events (Camp 3 often referred to their teams as the "Buckeye-Colonels," paying homage to both their home and work states), important work updates, editorials by enrollees and supervisors, and – perhaps most enjoyably – gossip and humor pages. The combination of oral histories compiled by various researchers in the 1980s and 90s and the camp newsletters provide a great deal of insight into the life and characters of CCC camps and enrollees.

For a brief time, Camp 1 was a desegregated camp, though with segregated barracks. When Camp 2 became available, Camp 1 housed the entirely African American Company 510 and the other three camps were white camps. The contributions of

Company 510 cannot be ignored. Not only was it the longest operating camp in Mammoth Cave, some of the hardest trail (above and below ground) as well as challenging utility work was completed by this camp. This work even involved becoming archaeological assistants, as 510 was the group involved in the discovery of and archaeology work surrounding "Lost John." During work in the "New Discovery" area, men from the 510 were tasked with digging the connection to Fairy Grotto and while doing so made several discoveries of significant new rooms and passages in this area. It has been noted that a greater degree of responsibility was given to African American enrollees at Mammoth Cave than to African Americans at sites in the deep south (Mammoth Cave existed in the fifth district of the CCC, also including Ohio, Indiana, etc.). For example, the 510 company at Mammoth Cave was an integral part of the forest fire prevention effort, whereas this was not the case for African American companies elsewhere. However, this does not mean that disparity did not exist between Camp 1 and the other camps. There is no indication in the narrative reports of assigning differing duties to the African American camp versus the white camps. The photo archive provides a slightly different story. While the photos indicate that every camp was involved in many common tasks, including trail and road creation, it is clear that each camp also tended to specialize in other tasks. With the exception of the "Lost John" archaeological work, there is not a single photo of African American enrollees engaged in more technical or skill-based assignments. While enrollees in Camps 2, 3, and 4 are seen building houses and cabins, assisting with masonry and carpentry, learning to become tree surgeons and using modern road engineering equipment, Camp 1 enrollees are shown digging ditches for utility pipes and building cement water reservoirs, as well as working the more labor-intensive cave trail projects.

Camp newsletters reveal rivalries between camps and tales of broken hearts of or by local women, but the available oral histories show very little evidence for meaningful friction between the camps or any bad feelings between locals and the CCC enrollees. Company 510 did face other challenges, however. Camp 1 repurposed older structures and was the first camp built, so its facilities lacked in comparison to the other camps. There was also the rumor that, because of its proximity to Salts Cave and its collapsed Pike Chapman entrance, the area was haunted. Initial poor management in Camp 1 contributed to particularly poor camp spirit. Later, under new leadership, Company 510 became one of the most highly rated companies in the entire fifth district. In 1938 Camp 3 was set to be closed and its company disbanded. At the same time, the Army wished to close the aging Camp 1 and provide 510 with nicer facilities. Mammoth Cave requested that Company 510 transfer from Camp 1 to the abandoned Camp 3 on Joppa Ridge. The local residents, protested this move so strongly that the company was briefly transferred to Fort Knox until the issue could be resolved. After a month of uncertainty the company moved back to Camp 1 on the Flint Ridge and the newer Camp 3 was disassembled and used for spare parts. Late during CCC efforts, the Company 510 was moved to Camp 2, but this move was well after the area was entirely owned by the park.

The creation of Mammoth Cave National Park serves as an interesting case study regarding the growth of the National Park Service during this era. In *Preserving Nature in the National Parks*, Sellars describes the evolution of thought concerning nature in parklands. The competing interests of wilderness conservation and public access and recreation were debated nationally as the Park Service added not only eastern National Parks, but also historic sites, battlefields, and recreation areas to their previously existing western “crown jewels.”

At Mammoth Cave these opposing forces created differing choices above and below ground. Sellars describes the desire to return parklands to the state of first European discovery. National parks could not be expected to erase Native American history and return nature to a condition before any human contact. However, plant and animal life should be restored and traces of Euro-American history erased to create the best approximation of the land as seen by the first European explorer or settler. At Mammoth Cave, this guideline was followed on the surface above the cave. Above ground nearly all evidence of Euro-American history was erased in favor of soil, forest, and wildlife restoration. Considerable effort was placed in planting over a million trees and building thousands of erosion control check dams. Forestry technicians closely monitored the progress from farmland to restored forest and regularly reported and mapped the results. Existing houses and structures were dismantled and removed (see below). The park service succeeded in preventing the Army Corps of Engineers from building a dam on the Green River that would affect the rivers and river life above and below the ground. Years were spent on the effort to reintroduce deer, turkeys, and beavers into the park. It is hard to think of driving through Mammoth Cave National Park today and not seeing numerous turkeys, but there was a time when great “hunts” took place to locate and track individual turkeys released in the park. One naturalist report details a weeklong trek through the forest to find traces and rumors of turkeys.

Tradition holds that families could see their houses burning as they drove down the road after relinquishing their property. The camp newsletters, CCC oral histories and the park narrative reports contain no evidence of house burning. All of these sources report that properties were dismantled and materials were salvaged for re-use. In two cases involving land owners who overstayed their allowed residency after sale and had ignored all efforts to evict, when it was learned they would be “in town” for the day park officials moved quickly to seize the property. In even these most contested and time dependent property seizures, the CCC workers dismantled and did not burn the houses and barns. Late in this period, salvaged materials were even sold at public auction. Earlier, however, these materials were used in park construction. Many of the chimneys of farmhouses were rebuilt as foundations in the residential and utility area. Wood was used in the construction of concrete structures and foundations, particularly for utility work. A fireplace mantle believed to pre-date the Civil War was saved for a number of years before finding a re-use in the Maple Springs ranger residence. (Photo 1 shows the Maples Springs ranger residence today. Originally, the “office room,” on the right side of this photo, was a porch.)

As nature in much of the proposed Mammoth Cave National Park was rebuilt to match the image of a pre-European Kentucky, key routes and public services were rebuilt, rerouted and improved to provide travelers with easy access to

significant areas. A residential village was constructed for park employees, including a rather monumental Superintendent's house. Nearby a utility area was built to include several workshops, garages, etc. One water reservoir after another, with accompanying pump houses and pipes, were built to accommodate the growing need for water in the park. Sewage systems were installed in the area of the hotel and in the residential area. New phone lines and exchanges were built. Roads determined necessary were straightened, flattened, and blacktopped, as were the ever-growing parking lots. Drainage control v-shaped stone culverts were built along many of the roads in the park (Photo 2). An artificial beach was installed on the Green River not far from the cave entrance. Visitor cabins, tennis and shuffleboard courts, a picnic area, and a new campground were built. A succession of new ferries were built and launched and the road and landing for the Mammoth Cave ferry near the Styx River was demolished in favor of a new road and landing for the ferry near the Echo River. In this case all four CCC camps contributed to the effort and there was a competition to see which camp would finish their section first. Shortly after construction of the new ferry landing at Echo River, storms and floods caused small landslides along the road cuts. This necessitated

further re-sculpting of the hillsides and the construction of slide control walls (Photo 3) on either side of the river. These erosion control structures work are still visible by everyone using the ferry to cross the river today. The Maple Spring Ranger station with residence and a fire station with ranger office comprised one of the last major structures built by the CCC in Mammoth Cave National Park. Many of the buildings constructed by the CCC in the park are now listed on the National Register of Historic Places.

Given the drive at this time to return nature to a pre-European state one is struck with the realization that no such work took place underground in the cave. One must conclude that to the Park Service, the cave was not viewed as "nature" but rather a source of recreation. Entrances and cave trails were built and greatly improved, additional lighting was added, and the experience was heavily promoted as a recreational experience through numerous media opportunities. During this time the Park Service also took custody of several historic sites and battlefields around the country and historic preservation becomes a new theme in parks. In the early 1940s, the first mention of a historic preservation initiative at Mammoth Cave is mentioned in the narrative reports regarding the need to preserve the remains of the saltpeter mining operations during the War of 1812.

Photos of this time are largely promotional in nature, often showing school groups, boy scouts, minor celebrities, veterans, and handicapped visitors and attractive women enjoying cave tours, lunch in the underground Snowball Dining Room, and beauty of the Frozen Niagara formation. Several radio broadcasts on Louisville, Nashville, and Cincinnati stations were made from within the cave to promote tourism.

Finally, competition from nearby show cave businesses not only led to legal action to curtail questionable tourism business practices, but also triggered renewed exploration of Mammoth Cave leading to the most significant discovery in nearly a century: Hanson and Hunt's "New Discovery." The discovery route was difficult, wet, and prone to flooding and so was not an option for tourism. Park Service geologist, Donald Hazellett, urged no development in New Discovery, but others felt that it would prove a public relations and tourism boom to the new National Park. A plan was developed to include three efforts in New Discovery: a new and modern artificial entrance was needed, cave trails would be constructed, and attempt would be made to drill through from one end of New Discovery to the nearby older tourist trail in the Fairy Grotto area. Work began immediately with much excitement. Care was taken to work carefully to prevent damage to the formations. Observers were posted to watch for signs of damage during blasting and the entrance was built to feature a double door air lock to prevent temperature and humidity changes that would rapidly destroy gypsum. But as World War II began and the CCC labor dwindled to only two smaller camps (Company 510, now at Camp 2, and Company 516), work in New Discovery slowed. The entrance and over a mile of trail was completed, but the connection to Fairy Grotto was never completed. In the spring of 1942 other more pressing projects on the surface drew workers away. April 29, 1942 marks the final day of work in New Discovery. Tools were left in place in the hopes that they would return next winter to complete the job; but by the next winter all of the CCC camps in Mammoth Cave were closed. For the past seventy years, New Discovery has been one of the rarest areas of Mammoth Cave to be seen, and has never been shown to tourists. In the end, Hazellett the geologist had his wish.

Now, though, CCC tools and work sites in New Discovery help us understand the process cave trail construction in other areas seen daily by tourists. For example, tool markings in the Fairy Grotto/Fossil Avenue dig areas look remarkably similar to tool markings in the sediment filled passage off Blackall Avenue near the route of the current Violet City Lantern tour. (Photo 4 shows CCC tool markings in sediment near Blackall Avenue.) Also in New Discovery is an example of a sediment chute (Photo 5) used to quickly transport sediment from a higher passage to the trail construction site. It is not hard, therefore, to imagine a similar chute used to help move sediment from Blackall to Main Cave for use in CCC trail construction past Chief City.

It is my hope that this work will begin a newfound appreciation of this period in the history of the Mammoth Cave region. It is a difficult period in Mammoth's history,

I drink to the days we've journeyed,
Afar on the wide green fields,
And I give my toast to the old camp's soul
And all it's meant to me.

I drink to the nights on the watch
In the glow of a yellow moon,
Where the cedar trees bow
With the hoot of an owl
In the breath of a summer breeze.

I lift a cup to the woods,
As one who has felt its call
And I pledge me deep,
To the faith I keep
In the love that I bear it all.

– excerpt from "Toast to Co. 516" by Charles Clifton, appearing in "Axe and Sledge," Volume 1, Number 1, August 1935.

but the results have had an amazing and far-reaching positive influence. It is correct for historians and others to turn a skeptical eye to the issues of eminent domain, big city versus local politics, and the dismissal of the legendary Black Guides from the guide force. There is, however, another story of this period: a story of building roads, essential buildings and services, hiking and caving trails, and reforestation and erosion control. Hundreds of people from hotel employees to National Park Rangers to engineers to CCC enrollees and local laborers spent many thousands of hours in a very noble endeavor. These men and women accomplished something that is nearly unthinkable today. They *made* a national park.

First Underground Photograph Taken in America

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Abstract

The presentation covers the work of Charles Waldack in Mammoth Cave. Waldack took the first underground photographs in America. He was the pioneer of using magnesium as a light source for cave photography. It explores the who, why, when, where and how of his images in the cave. It covers the recreation of his stereo views in the cave showing the same views taken nearly 150 years apart.

Mammoth Cave in Poetry: Davis McCombs' *Ultima Thule*

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Abstract

Davis McCombs, former Mammoth Cave park ranger, received the Yale Younger Poets Award for *Ultima Thule*, his collection of poems based on his experiences in and with Mammoth Cave, not only of his actual experiences as ranger and cave explorer, but also of the history of the cave, including poems in the voice of Stephen Bishop, cave explorer, cave guide, and also a slave. The detail of McCombs' examination produces what poet W.S. Merwin called "a grave, attentive holding of a light." In a sense, his poetry illuminates the cave the way ancient torches and modern lighting have done. This presentation might seem an odd choice for this conference, but the poetry of the cave is truly a part of it, and listeners can add a different dimension to what they already know to be a natural wonder. The purpose of this presentation will be to introduce the poems and their themes, to share the poems to the extent that time allows, and to connect the poetry with the history, science, and geography of the cave.

From Board Games to Tobacco Products: U.S. Patents Related to Mammoth Cave

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Abstract

The archives of the U.S. Patent Office offer a unique window into the location, creativity, and entrepreneurial spirit of millions of inventors. What might the Patent Office records tell us about Mammoth Cave? A search of patents issued since 1836 resulted in 34 inventions that mention Mammoth Cave in their descriptions. Of these 34 patents, four were for technical aspects of cave environments such as ventilation, six were games or educational products, and 23 were related to Mammoth Cave Twist, a brand of chewing tobacco. The first Mammoth Cave-related patent was granted in 1915 for a board game and the most recent patent (2011) for tobacco. Also examined were 10 patents granted to Edmonson County residents prior to the establishment of Mammoth Cave National Park. Edmonson County patents were not directly related to Mammoth Cave but rather reflected local agricultural and technological needs of residents prior to the Park's founding.

History of Crawling Tours at Mammoth Cave

Janet Bass Smith[1]

[1] Interpretation, Mammoth Cave National Park

Abstract

Currently three crawling tours are offered at Mammoth Cave: Wild Cave (six hours) for visitors ages sixteen and older, Introduction to Caving (three hours and 15 minutes) for visitors ages 10 and older (under 18 must be with an adult), and Trog (two hours and 30 minutes) for children only, ages eight through twelve. These tours are discussed in detail below. Maps for each tour are included at the end of the paper. This history relates the beginnings of each tour.

Wild Cave

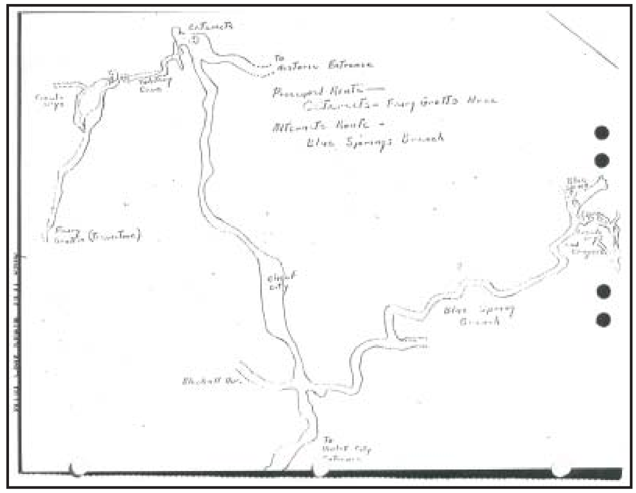
The Wild Cave tour began on December 29, 1970 with a memo from Chief of Interpretation and Resource Management, Edwin Rothfuss, to Park technician, Keith Morgan, asking him to develop a spelunking trip. Morgan was given certain suggested guidelines: it would be for 10 people over 15 years old, it would be offered twice daily from June 4 thru Sept. 4, the length would be two to three hours with interpretation of geology, biology, research, caving techniques, and safety, and each trip would involve some crawling. The aim would be to give visitors a taste of wild caving. Morgan was to find a suitable cave, develop a trip and story to be told, develop a budget, select and order equipment. He was to be assisted by Rangers Clive Pinnix and/or Bill Ritter. Ray France and Ed Rothfuss would assist on overall planning and budgeting as needed. If approved, the tour would start in late May, 1971 when Morgan was to select one or two seasonals, train them, then guide and supervise this trip throughout the summer. He was then to submit a final evaluation report the next fall.

Keith Morgan submitted a progress report to Rothfuss on January 16, 1971. Morgan, Pinnnix and Ritter had visited four caves: Long's, Great Onyx, Little Beauty, and White's. Each of these was evaluated in detail, and none was deemed suitable due to transportation problems, no crawlways, and/or few passages of interest.

On February 11, 1971 Ed Rothfuss wrote to Dr. Joseph K. Davidson, the president of the Cave Research Foundation and a professor at Ohio State University, asking for suggestions in planning a spelunking trip. Dr. Davidson responded to this request on March 23, 1971, saying that he had reviewed with several CRF members the objectives of the proposed wild cave trip, and they suggested areas that "seem to us to fit your objectives well," and listed the following:

1. Either end of Robertson Ave. in Mammoth Cave. Grand Central end is dry and pleasant, but Cathedral Domes end has much more variety in cave features.
2. Other areas near the Frozen Niagara Entrance, such as College Heights Ave.
3. Ganter Cave. Boat trip to entrance provides appealing variety for the trip.
4. Proctor Cave. Great variety of cave features in a small area makes this cave especially attractive.
5. Smith Valley Cave. Cedar Sink gives added opportunity for interpretation.

He said other areas would be suitable, but some, such as Nicholson Avenue, were rather remote. They recommended Proctor, Ganter, and Smith Valley Caves, but noted they had access problems. CRF especially recommended Proctor cave, stating that "the fifteen-minute walk from the road is easy, and periodic mowing of grass in the trail would keep the tick problem at a minimum." Davidson also said that "as areas are selected for the wild caving trips we hope that regions containing Indian artifactual material or large populations of bats be avoided."



Map #1: Wild Cave 1971 only, Violet City area

On April 12 Ranger Keith Morgan again reported to Chief Guide Rothfuss about the progress his team had made. They had considered three major cave areas: Running Branch, Ganter, and Frozen Niagara. They determined that the first two were inaccessible. The Frozen Niagara area might be developed into a good tour, but it had some bad characteristics. However, the team did recommend using this area as the initial experimental area while looking for other possible locations.

He also submitted suggested forms for a response letter to answer inquiries concerning the wild cave tour, a pass-waiver form to be used as a ticket and waiver of rights to be signed by all persons on the tour, a reservation form for organized groups of five or more persons, and a handout sheet to be made available to interested persons after the tour. Copies of those are in the Mammoth Cave files.

While he was gone on another assignment, an alternate route was suggested since the Frozen Niagara section was thought to be too congested with other tours. This route was Fairy Grotto behind the Cataracts. Later "Blue Springs" was also used as a route. These areas are reached by going in the Violet City Entrance, and involve a long walk before reaching an area of crawling. (See Map #1) Because Keith Morgan, who was to guide and supervise the tour, was gone for six weeks, the tour was not started until July 7, 1971, and the above route was used. Part of the delay was the cashier's difficulty in finding appropriate tickets. Finally the cashier used surplus tickets from the All Day Tour of several years before.

Keith Morgan's report to the superintendent evaluating the wild cave tour, dated September 29, 1971, is in the Mammoth Cave files. Following is a summary of this evaluation report.

In Section I Ranger Morgan defines the wild cave tour as an introduction to speleology (the science of cave study), and spelunking (the sport of caving). In Section II he states that the reasons for having the tour were FUN (his caps), education, and to give the visitors an opportunity to experience the cave in a setting without the crowds of the usual tours. The history of the tour (covered above) is discussed in Section III.

In Section IV he discusses the operations. The tour was offered twice daily, at 10:00 a.m. and 2:00 p.m. and cost $2, which included a fifty-cent bus fee. The tour lasted three hours, including a brief orientation session at the Visitor's Center during which helmet, battery headlamps, and kneepads were provided. Approximately two and one-half hours were spent underground. The tour was limited to ten people, sixteen or older, in good physical condition. Suggested appropriate dress included sturdy shoes, old clothes, and gloves.

Guides were selected from volunteers based on their ability as cavers, experience as interpreters, and desire to lead such a tour. Two GS-5 seasonal park guides, a man and a woman, and a GS-6 Park Technician (who also helped supervise the trip) led the tours. He recommended that future appointments of wild cave tour leaders should be made from volunteers who were adaptable to change and had an interest in spelunking.

In Section V, dealing with the success of the tour, he reported the "unsolicited visitor expressions of interest indicate the tour was a tremendous success." He went on to state that there were no complaints, and many said they would pay twice the cave fee for the experience. The small group size helped make it a good experience. Another great success was the lack of accidents and tort claims.

Section VI dealt with special problems. Equipment: helmets did not have chin straps headlamps had cables going from the battery pack to the light, and this cable snagged on protruding rocks. Also, the packs often fell off belts. He suggested a self-contained assembly attached directly to the helmet, or with a battery pack permanently attached to a belt that could be issued, along with the helmet, to each visitor. The kneepads were inadequate, and he suggested heavier industrial pads.

The second problem was the lack of time. More time was consumed getting to the wild cave area than was used seeing it and very little time remained for interpretation. The tour route, while interesting, involved a great deal of walking through developed passages, which was not the original intent of the tour. He suggested a longer tour, and a different route or cave.

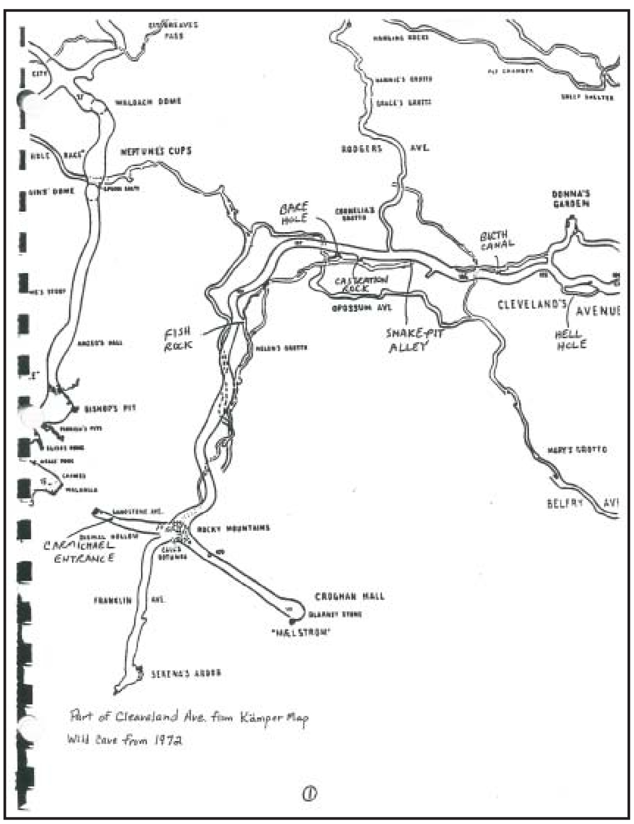
The third problem was employee opposition to the tour itself. A few employees severely objected to the tour because they felt the Park was not treating all visitors with equal fairness by sending ten people with one guide while thousands of visitors on other tours were forced to go with three guides and 200 people. They stated it was bad utilization of manpower, but "did not seem to realize that without the special tour another man would have been dropped from payroll, leaving other tours the same number of guides." Some of these critics were ticket sellers who had made their opposition known to the public.

Morgan goes into detail about the financial aspect of the tour, and reported that the tour lost approximately $1500 the first year, partly because it wasn't started until July, but an extra guide had been hired. During the time when he was not guiding wild cave, he was guiding other tours, but it still was reported as a loss for wild cave because no tickets were sold to offset the salary. He noted that the equipment purchased could still be used, with batteries and new knee pads being the only future cost. He again recommended that the tour be continued as a longer tour, using a different route.

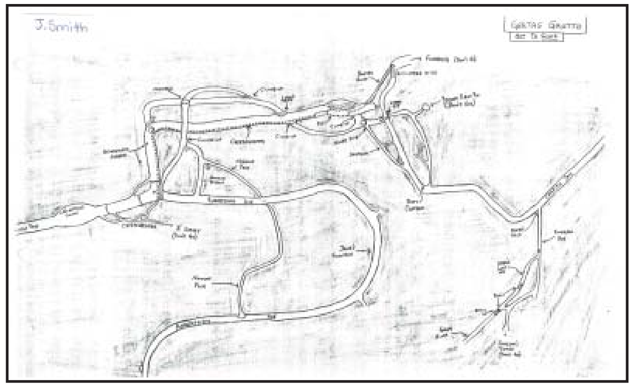
In the file is a hand-written letter from Miriam Ash, one of the wild cave guides, to Keith Morgan evaluating the tour. Ranger Ash stated that the tour was a great success as far as visitors were concerned. However, she suggested the use of a different area and also expressed the need for chin straps for the helmets and different knee pads. She also suggested presenting visitors at the conclusion of the trip with a certificate indicating their advancement to the title of spelunker, and having available an up-to-date listing of the NSS Grottos for those people interested in continuing caving activities.

In 1972, after that first summer, a group of rangers who had been selected as wild cave guides were taken into the cave with Chief Guide Lewis Cutliff to find an appropriate route that would last the right amount of time. These guides were Dave McGinnis, Ed Green, Brenda Brassel (who later married Dave), Sharon Madison, and Marvin Witcher. They went in Carmichael Entrance and came out Frozen Niagara, basically going through the route still in use today. The Kämper map was used as a guide. (See Maps #2 and #3)

Within those areas are many variations. It is difficult, if not impossible, to ascertain which passages were used in the early tours. Many of the earlier guides do not remember the names of the passages they used, and some that are now used may have had a different name or no name at all. In the complete copy of this research is a list of the places that are possible, names of those passages, and, when known, who named them. For the first few years the Mole Hole



Map #2: Wild Cave 1972 to present, Cleaveland Ave. from Kämper map



Map #3: Wild Cave 1972 to present, Gerta's Grotto, not to scale

was required. Now certain areas are off limits, but no areas are mandatory. In 1996, when I first started guiding Wild Cave, the tour came out the Keyhole and climbed up to College Heights. This is the exit now used by the Introduction to Caving Tour, and Wild Cave has stopped using it to avoid congestion in that area when Intro and Wild Cave are in Fox Ave. at the same time. Currently Wild Cave exits up Big Break above Grand Central Station, or through Fox Ave. to the Compass Needle Climbup.

In the mid 1980s Chief Guide Joe McGown made George Corrie the Wild Cave Coordinator. At that time guides had to furnish their own packs and most of the guides provided their own helmets. Most guides purchased their own kneepads or used the Rockmaster kneepads that were issued to the visitors. Corrie suggested that we give the visitor a disposable helmet and purchased new lights for the guides and visitors. Corrie also purchased Petzel helmets for the guides, although some guides continued to use their own. He purchased packs and first aid kits for the guides, and placed first aid kits along the wild cave route. The disposable helmets for visitors were eventually replaced by higher quality helmets. Corrie remained the primary lead person for crawling tours for about ten more years. Currently

Chuck DeCroix oversees and maintains the helmets, lights, and batteries.

Except for the basic route, many details of the tour have changed over the years. Ticket prices have continued to rise and currently are $48. Since 1998, due to safety concerns caused by several accidents, two guides are required at all times, over-the-ankle footwear with aggressive tread is mandatory, and certain areas of the tour route have been deemed off limits.

The White Nose Syndrome (WNS) protocol has completely changed the dynamics of all the crawling tours. Now visitors are taken to the "dorms" where they are issued coveralls and equipment, and boots must be soaked in water/Lysol solution at the end of the tour. This has impacted the time of the tour, sometimes starting about thirty minutes later getting into the cave.

In July, 2012, WKYU-PBS's Mainstreet segment on the Wild Cave Tour, led by Jackie Wheet, won an Emmy award.

Guide Data:

First rangers to guide in Violet City (1971): Keith Morgan, Miriam Ash

First rangers to guide in Cleaveland Ave area to Frozen Niagara (1972): Dave McGinnis, Ed Green, Marvin Witcher, Brenda Brassel McGinnis, Sharon Madison Ganci

Longest continuous guiding: Keven Neff, guided from 1976 to 2010

Oldest person to guide: Janet Bass Smith, guided from 1995-2010 (age 74)

Trog Tour

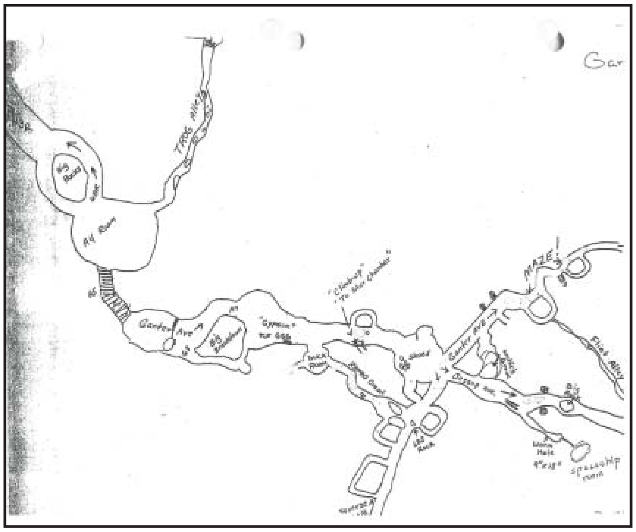
The Trog tour began in 1974 when Guide Brenda McGinnis, at the request of the Chief of Interpretation, planned the tour, and was the first guide. It was two and one-half hours, and was designed for children ages six to twelve. Later the lower age was raised to eight. At first there was only one guide; now two guides are mandatory regardless of the number of participants. A minimum number of two visitors is necessary for the trip to go. Currently the tour is offered in the summer, or by special arrangement for selected groups at any time. It is limited to twelve participants between the ages of eight and twelve. Before the White Nose Protocol began in 2010, visitors were requested to wear ankle length, durable pants, and sturdy shoes. Beginning with the 2010 season, participants are loaned coveralls to wear during the trip. An adult chaperon must be present for the first fifteen minutes of the activity, and must pick up children at the end of the activity. Before the white nose precautions, participants were allowed to keep the helmet after the trip. The length of the tour has been increased 30 minutes (to 2 ½ hrs.) to allow time for fitting children with coveralls.

The first tours went to Dixon Cave or White Cave. The participants were met at the Amphitheatre, and walked to the cave. Because of the long surface walk to and from the cave, the walk was used as a means of teaching the participants the relationship between the surface and the cave. Later the guides had the choice of White Cave or Gratz Ave., under Gothic Ave. Since 2009 the tour always goes to Ganter Ave., entering through Trog Alley at the bottom of the Steps of Time, or through the opening to the left of the trail in Wooden Bowl Room. (see Map #4)

Explorer Tour

In 1989 Zona Cetera and Keven Neff suggested, and in the spring of 1990 made a formal request for a crawling tour to fill the age gap between the Trog Tour (8 to 12 year olds), and the Wild Cave Tour (minimum age of 16). They suggested Ganter Ave. as a possible route.

The tour was offered in the summers of 1990, 1991, and possibly 1992. It was replaced by the Introduction to Caving



Map #4: Trog Tour 2009 to present, Ganter Ave.

Tour in 1993. It was a three and one-half hour trip, developed as a crawling tour for children from 13 to 15 years of age. The route was the Historic Entrance to the Wooden Bowl Room, and then it exited the Wooden Bowl Room via Lost Ave. to the Sick Room, took Harvey's Avenue to Main Cave, then to the drop-down in Indian Ave. to Ganter Ave, and exited below the Steps of Time. It then exited back around Giant's Coffin and returned to the Historic Entrance. (See map.)

The tour was offered each Saturday and Sunday during the summer season. The cost was $3 per person, and it was limited to 12 participants and one guide. Each participant had to be in good physical condition and able to crawl and climb. Each participant was asked to wear old clothes, sturdy shoes (boots were suggested), and a belt. Gloves were recommended. It was discontinued because the demand was not there to warrant its continuation.

Introduction to Caving Tour

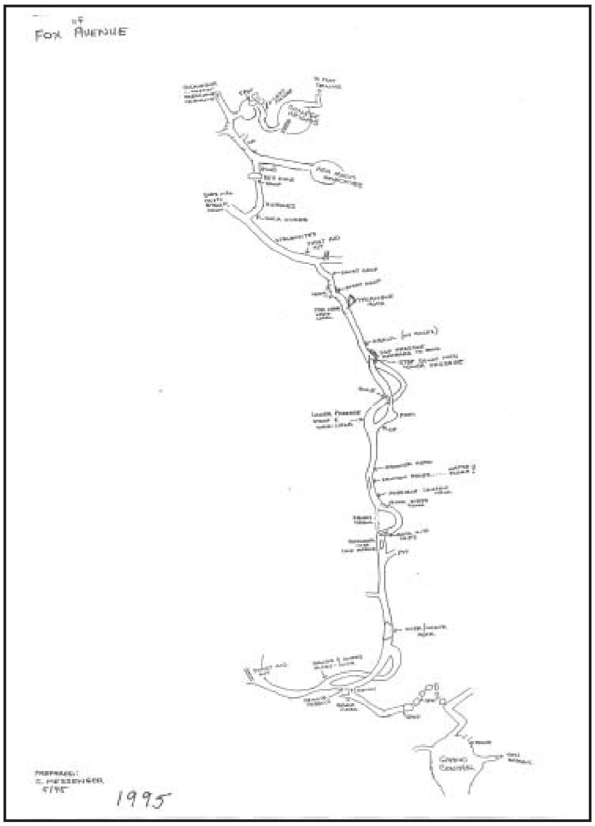
The Introduction to Caving Tour started in 1993 as a replacement for the Explorer Tour, and was to serve as an introduction to safe and correct caving techniques. The tour began with a slide presentation in the auditorium which included information about the hydrological creation of caves. This was followed by a demonstration of safe caving equipment, rules, and safe caving techniques. No one seems to know exactly when the slide program was discontinued, but probably around 1996 or 1997.

The tour was designed to be a family tour. In 1993 it was limited to twenty people, was three hours and fifteen minutes in length, and covered one and one-half miles. The park furnished a helmet, light, and kneepads for the visitor, and the visitor was allowed to keep the helmet. Participants were requested to wear jean type pants with a belt, and sturdy shoes.

Since 1993 the number of visitors has remained at twenty, but the age limit has changed. According to the ISP dated 1993, visitors could be as young as eight, but sixteen-year-olds and younger had to be accompanied by an adult. An ISP dated February, 1994 again states that this activity was limited to 20 participants, at least eight years of age (under sixteen must be accompanied by an adult). The ISP dated February 1996 lists the minimum age as ten years, and those under sixteen must be accompanied by an adult. The ISP dated March 2009 keeps the minimum age as ten years, but now participants under eighteen must be accompanied by an adult. The 1993 ISP states that the trip would trail when there were six or more participants. All following ISPs state the trip always trails. In 2009 boots were required, and since the white nose protocol, visitors are no longer allowed to keep the helmet

In 1993, 1994, and 1995, the tour route was an area off Cleaveland Ave. The group came in the Carmichael Entrance, and could exit either at Carmichael, or go up the elevator. The route covered the Maelstrom at the Rocky Mountains; Serena's Arbor was an option. (see map)

In 1996 the tour route was changed to Fox Ave. and is currently in that area. The tour enters through the New Entrance, crawls through a hole off the Subway called The Test Hole, leading into Grand Central Station. The group then climbs down Big Break into Big Gypsum Ave. and into Fox Ave. (see Map #5)



Map #5: Introduction to Caving Tour 1994 to present, Fox Ave. under Big Break

Misconceptions Among Us: Evaluating Informal Karst Education in the United States and Abroad

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Abstract

Data collected through archival research, personal communication, electronic surveys, and field-based research at four US show caves, including Mammoth Cave, indicate the existence of multiple misconceptions about education in informal learning settings. For instance, although karst educational endeavors are seemingly abundant, the number of these programs directed at children far outnumbers the quantity of programs available to adult learners. Moreover, over 54% of educational pursuits focus solely on caves, not karst terrains. Operators of many tourism facilities lack an understanding of learning outcomes from guided tour experiences or an understanding of how best to develop cave tours. Data also reveal abundant disconnects between visitor desires for education and tour guide and manager opinions about the subject. This body of data is alarming in that it reveals managers and educators may be misinformed about educational pursuits at karst attractions, and alternative techniques to enhance educational endeavors can make a difference.

Using Interactive Simulation to Extend Access to Learning along the Historic Tour Route of Mammoth Cave National Park

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Abstract
This poster presentation displays work of a current project to address the problem of limited inclusion to field-based learning experiences for students with physical disabilities. Led by researchers at Georgia State University, Ohio State University and Mammoth Cave International Center for Science and Learning, the overall objective of the project is through integration of emerging simulation technologies and techniques, to provide a rich virtual environment of a geological field site for students with mobility impairments. Through the development of a synthetic field-based module that employs a virtual environment that interchangeably uses two and three-dimensional representation for presenting an alternative to field experience, this project will assess the effectiveness in engaging the student community and its efficacy in the curriculum when used as an alternative representation of field experience. The expected outcome is that the emulation would preclude the need for physical presence within the traditional field site, and provide adequate pedagogical representation for content transfer. Additionally, creating such an environment will impact all able-bodied students by providing supplemental resources that can both precede a traditional field experience and allow for visitors to re-examine a field site long after a field trip, in both current formal and informal educational settings. Based on the identified need to accommodate students with mobility impairments in field-based instructional experiences, this talk will present a virtual recreation of Mammoth Cave National Park, describing the potential for including all students in remotely accessing cave and karst field studies, regardless of their physical abilities.

Preservice Elementary Teachers Learning about Karst at Mammoth Cave National Park

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Abstract
All Preservice elementary science methods students at Western Kentucky University participate in a one-day or two-day experience at Mammoth Cave National Park. This trip has occurred over the past seven semesters. Through this experience, students gain knowledge about their local unique karst environment.

Students participate in activities which inform them about the environment at Mammoth Cave. Using their hands to form a model of karst topography, students begin to understand how sinkholes and disappearing streams receive runoff and precipitation. Before viewing a cave, students are refreshed on the three types of rock and the three main rocks found at Mammoth Cave. Students touch and visually compare the three types of rock. They learn how shale, limestone and sandstone are formed and how these rocks make up various levels of the cave, either above or below ground.

On the walk to the Historic Entrance, observations of a disappearing stream provide evidence to where water travels in this area. On rainy days or on days where rain has recently occurred, students see water trickling in the stream, but on days where rain is absent, water is absent in this geologic feature. Students climb the observation overlook to view a sinkhole. They learn how sinkholes are formed and that this sinkhole formerly was connected to the Historic Entrance. This also shows them changes to the environment. Students touch horn coral on the rocks and see the sandstone sparkle in the sun. Just outside of the entrance, students view the layers of the rock and see how shale and sandstone protect the cave.

Students participating in the overnight trip extend their learning, participating in activities from 8:30 am until 8:30 pm on Friday and again from 8:00 am until about 3:00 pm on Saturday. Project WET has been integrated into learning about karst because water is such a vital natural resource and important component in the cave ecosystem. On Friday, students view the Historic Entrance. Students are given unprecedented access to a region of the cave where they are given permission to leave the visitor's trail and use their headlamps and magnifying lenses to make closer observations of the cave. Students are doing an open ended inquiry where they are determining their learning. Students are given a sheet where they write down their observations and write their own questions based on these observations. At the Star Chamber, students share their observations and questions. Cheryl Messenger and Jeanine Huss, the workshop facilitators, write down the questions and provide fact sheets with answers to some of the questions. In a classroom, students might be able to actually answer these questions on their own, but in the parameters of a cave, it is easier to provide answers. Some students prefer this type of learning because they determine the topic and depth of learning. Other students prefer the more typical lecture provided by interpreters. Following the questioning and answer session, students hear "Illusions" by Ralph Waldo Emerson, who wrote the poem in the Star Chamber on his visit to Mammoth Cave. Students also view the illusion mentioned in Emerson's writing, a sunrise. Two Mammoth Cave personnel use lanterns to create the sunrise.

In the evening, students learn about a variety of maps used at Mammoth Cave National Park. Using topographic maps of the Historic Entrance, students create their own topographic map using colored foam board. Students use their created maps and walk part of the map the following day. Students learn about point and nonpoint pollution and about the amount of water available to each person on the earth.

Recycling is a mandate for the national park and students learn to recycle their plates and utensils over the weekend trip. They scrape food into a container to be used for compost and recycle their plastic and paper products. Reusing wash clothes every trip and towels for art projects also emphasizes an easy way to reduce some of the trash we typically consume. Students see the reduction of waste when they use less than one trash bag over the two days with thirty participants.

On day two, participants view Great Onyx Cave. This cave is used to study the living things at the park. Students often see cave salamanders, two types of cave crickets, the blind cave beetle and one type of bat. Students marvel at the stalagmites and stalactites and note how wet the cave is in the area where these cave features form. Proceeding further in the Great Onyx, students notice how dry the cave becomes and notice the lack of animals in the dry area. On day two, students begin to make connections with their observations on the first day. The soot covering the gypsum on the first day is now soot-free. Students see the mineral growing in cracks, sometimes turning a rust color and observe the snowball and flower formations deeper in the cave.

Students focus their observations on their personal interests or curiosities. Some groups focus on the human aspect and compare the boardwalk, lights, and prehistoric humans in the Historic Cave to the lack of boardwalk and lights and no evidence of early prehistoric people in the second cave. Other groups focus more on the animal life and question how bats enter and exit the cave and why bats are seen individually. Still other groups focus more of their questions on the geology and how water has created two very different caves.

One day participants, in contrast, learn about karst topography and the three types of rocks. They take the same walk as the two day participants and also view the sinking stream and sinkhole. Because this trip is 8:30 am until 3:00 pm, students view the Historic Entrance cave and do a few other activities before leaving. This shortens the time for students to reflect on their learning and to build on their experiences.

Preservice students participating in the overnight trip, funded the past three years through the National Parks Foundation and this year funded by Dr. Sam Evans in the College of Education and Behavioral Sciences, show an increase in student understanding, over the one-day trip participants. Participants in both trips take the Environmental Education Efficacy Belief Instrument (EEEBI: Sia, 1992) pretest the first day of the semester and take the posttest at the end of their Mammoth Cave trip. Both groups increase their personal environmental teaching efficacy (PETE). Two-day trip participants show increased complexity in their Above/Below Ground Drawings and concept maps and general cave and geology knowledge over the one-day participants. Implications for this research provide evidence on extended trips being preferred to shorter visits because students' knowledge increased.

Effects of Prescribed Fire on Mammoth Cave National Park's Oak-Hickory Vegetation: A Decade of Fire Monitoring

Jesse A. Burton[1]

[1] Barrens to Bayous Fire Monitoring Network, Natchez Trace Parkway Fire Management Team

Abstract

Mammoth Cave National Park contains a spectacular suite of plant communities; many of which are dependent on wildland fire as a disturbance process for their preservation. Over a third of the park is dominated by oak-hickory forests and woodlands. Fire is a fundamental process in the development and maintenance of this important community type. Since the park's first prescribed fire in 2002, 16,700 acres of forest, woodlands, and barrens have been treated with prescribed fire. Initial goals for the prescribed fires were to reduce the density of tree saplings in the understory and increase the cover of herbaceous herbs in the understory. After a single burn, wildland fuel loading was reduced by 18%, density of understory trees (dbh < 15cm) was reduced by more than 30%, and mean cover of graminoid species increased from < 0.01% to 5.2%.

Introduction

Containing approximately 53,000 acres, Mammoth Cave National Park (MACA) preserves a large area of diverse vegetation communities. Plateaus and hills broken by sinkholes, rocky glades, and the Green River characterize the relatively rugged topography of the park. Areas of both acidic and calcareous soils are common throughout this park. Due to the karst topography; water rapidly filters below the surface, resulting in not only the vast cave system below the surface, but also very little surface flow in streambeds (USDI NPS 2006). This lack of surface water would have limited the natural firebreaks on the MACA landscape, particularly south of the Green River. Prior to European settlement, and subsequent segmentation of the landscape, fire would have moved unbound until reaching rivers, excessively rocky bluffs and glades, or areas recently burned. While generally accepted that fire return intervals were maintained by Native Americans throughout the Holocene, Ray (1997) proposed that lightning-caused fires alone could have accounted for a pyrogenic landscape in this park.

These geologic and topographic factors greatly influence the vegetation found at any given area within the park (Olson & Noble 2005). The interaction of fire with the potential vegetation and topography would have greatly modified and maintained a variety of plant communities in this diverse ecosystem. Many of today's dominant species and ecosystems in the Central Hardwoods landscape likely owe their importance to the persistence of fire and its use by Native Americans since the Pleistocene (Anderson 1983, Nowacki & Abrams 2008). Historic and archeological evidence at MACA suggests that areas of prairie, savanna, and woodlands were commonplace, where they are rare today (Shull 1921, Ray 1997, Olson 1998, USDI NPS 2001, Cecil Frost - personal communication). The entire park contains some of the greatest biological diversity in the state of Kentucky; however, without natural and anthropogenic fire, unique communities and their associated species are at risk (Seymore 1997).

Although there are many vegetative alliances at this park, roughly one third of MACA is dominated by upland oak and oak-hickory vegetation (USDI NPS 1934, Olson & Ghitter 2000), a collective forest community that is currently showing significant declines due to a lack of disturbance processes necessary to maintain the dominance of fire-tolerant tree and herbaceous species associated with this community (Nowacki & Abrams 2008, Hutchinson 2006). The oak-hickory vegetation type and its associated dominant tree species are widely recognized as a disturbance dependent community, maintained by shade intolerant species that are capable of resprouting for decades and replacing overstory individual trees only if continually burned (Abrams 1992, Iverson et al. 2008, Buchanan & Hart 2012, Hutchinson et al. 2012).

Like many National Park Service (NPS) units in the Southeast, prescribed fire has been used at MACA since 1999 to maintain and restore fire-adapted ecosystems at MACA by reducing hazardous fuel levels, limiting encroachment of invasive woody species, and restoring the historical structure of plant communities on the landscape. As of May 2012, roughly 16,700 acres, roughly 30% of the park, have been treated with one to four prescribed fires. Including units that have been treated more than once, MACA has carried out some 22,752 acres of prescribed fire treatments. This park's Fire Management Plan and Fire Monitoring Plan identify management goals and objectives for the park, which indicate the need for continued fire management activities, including prescribed burning. The policy of the NPS requires that all prescribed fire activities have thorough plans that are accompanied by long-term monitoring (USDI NPS 2008). Fire effects monitoring at MACA began in 2000 and, since that time, has worked to ensure that the park's pyrogenic communities are being restored and biodiversity protected. While vegetation monitoring is not designed to answer all questions concerning fire ecology, short and long-term monitoring is part of the adaptive management cycle and provides a basis for altering management actions (USDI NPS 2003).

Methods

Monitoring Design

Fire effects monitoring at Mammoth Cave National Park follows the design outlined by the NPS Fire Monitoring Handbook (FMH) (USDI NPS 2003). Permanent vegetation/fuels monitoring plots were stratified randomly within target vegetation types, installed and read prior to fire treatments, read immediately after a fire, and are subsequently read on standard monitoring schedules of one, two, and five growing seasons after the fire. This vegetation and fuel monitoring methodology is outlined in the FMH and the plots are referred to as FMH plots. From 2000 to 2012, 38 permanently installed FMH plots were placed within MACA. Only twelve (N=12) of these plots were utilized for the analysis in this manuscript as they were dominated by oaks and hickories (*Quercus* spp. and *Carya* spp.; percent of total overstory basal area > 50%) and have been treated with prescribed fire (Figure 1). Ten of these plots have experienced at least one growing season since a prescribed fire (thus N = 10 for vegetation analysis), and only two have experienced a second fire. Selected plots were installed in various seasons of the year ranging from March through early November; however, each plot is subsequently read at the same season/month as its initial installation. One plot for this study was read in March (spring), three in June (early growing season), and eight from the last of September through early November (end of growing season). Plots are 20 x 50 m in size, but subsampling is used depending upon the variable being measured (USDI NPS 2013).

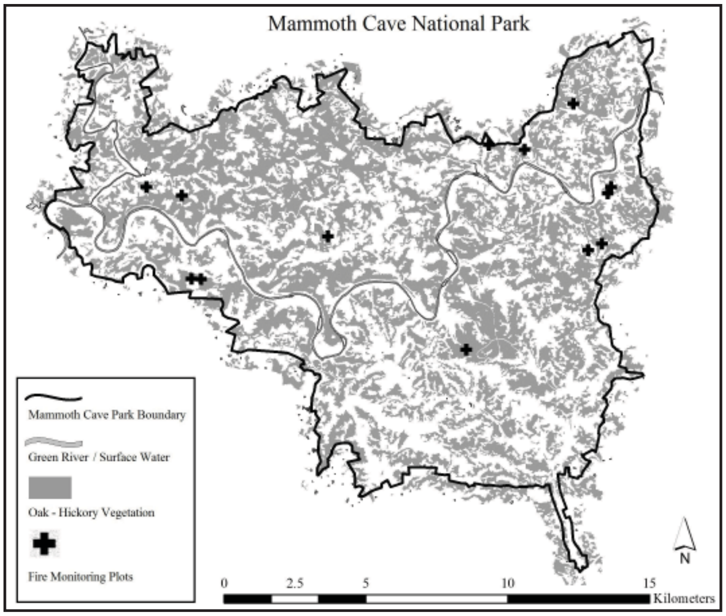

Figure 1: Mammoth Cave National Park boundary, predicted area currently dominated by mature oak-hickory vegetation, and FMH plots dominated by upland oak and hickory species.

Prescribed Fires
FMH plots utilized for this study were treated in nine separate prescribed fires within eight burn units. All plots were treated at least once with prescribed fire and only two plots were treated twice. The first fire monitored was April 2, 2002 and the most recent March 21, 2012. All prescribed fires took place late March and late April. Burn severities reported are indices from a coding matrix found in the FMH, with 1 representing severely burned to 5 representing unburned (USDI NPS, 2003, p. 110). Mean scorch and char values given represent percentages and heights of individual overstory trees that have measurable impacts. For example, scorch values are not recorded for hardwoods that are completely dormant, therefore, estimation of scorch and char are likely overestimates of actual impacts of any given fire.

Data Analyses
Graphical representations of selected results utilize mean values and error bars represent standard error of the mean. For the purposes of this paper, no values were transformed. Two-tailed paired t-tests were performed on the same plots to test differences before and after prescribed fires, as well as later read schedules for all variables discussed. The α level for all statistical tests was 0.05.

Results

Fire Severity
Average burn severity was 3.4 ± 0.3 (SE) for substrate (soil, duff, litter, and woody debris) and 3.6 ± 0.2 for vegetation immediately after the first burn (N = 12), representative of an intermediate stage between lightly burned and scorched. Average burn severity was 4.4 ± 0.5 and 3.7 ± 0.3 for substrate and vegetation, respectively, after the second burn (N = 2). Average scorch percent of live tree canopy was 4.3% ± 1.4 (N = 12) and average scorch height was 2.1 m ± 0.6. Mean of maximum char height of the overstory trees' trunks was 0.5 m ± 0.09.

Overstory Trees
Basal area (BA) ranged from 13.8 to 43.7 m^2 ha^{-1}. Although eight of ten plots showed increases in total overstory BA, average total BA for these sites was approximately 31 m^2 ha^{-1} and was not significantly changed by a single prescribed fire (N = 10, P = 0.07). . Overstory tree density ranged from 220 to 550 trees ha^{-1} with a mean density of 340 trees ha^{-1} prior to burning. One growing season after the burn, average density was 334 trees ha^{-1}; however, this change was not significant (P = 0.22).

Understory Trees
Over 90% of the trees measured in the understory were not from the two genera dominant in the overstory, oaks and

hickories (Figure 2). The average density of understory trees was 568 stems ha^{-1} prior to prescribed fires (N = 10), and was an average of 518 and 376 stems ha^{-1} one and five years post burn (N = 10 and N = 5). Albeit small, average plot reduction of the small trees was 10% one growing season after the first burn, a significant reduction (P = 0.01, Figure 3). Although highly variable, five growing seasons after initial fire, the average plot reduction was 32% (P = 0.11).

Seedling and Resprouting Trees
Mean density of total tree seedlings and resprouts is 33,820, 38,060, and 41,840 stems ha^{-1} for before, one year after, and five years after prescribed fire, respectively. No significant change was detected from pre-burn densities to one year or five years post-burn (N = 10, P = 0.60 and N = 5, P = 0.40 respectively). Before fire, approximately 66% of the tree species measured in the understory were species other than oaks and hickories. Five years post-burn this proportion has changed to roughly 50%; however, when oaks and hickory saplings are removed from the analysis, there was still no significant change in density.

Herbaceous Plant Cover
Average total plant cover measured by point intercept was 45% with no significant change after prescribed fire (N = 10, P = 0.74). Mean herbaceous plant cover (all plants excluding woody trees, shrubs, and

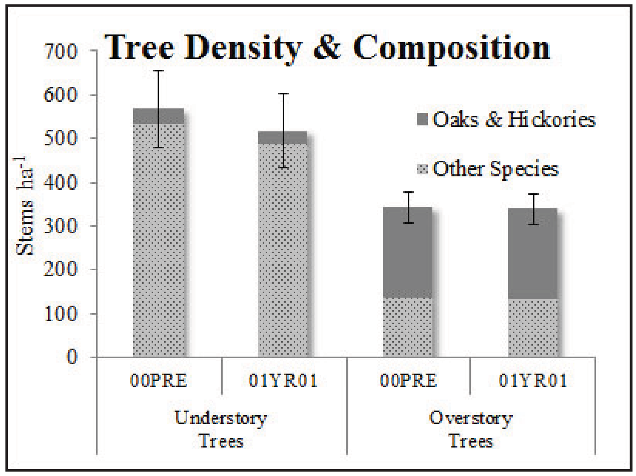

Figure 3: Density of understory and overstory trees for oak-hickory FMH plots. Mean density of understory trees was significantly reduced, while overstory density remained unchanged.

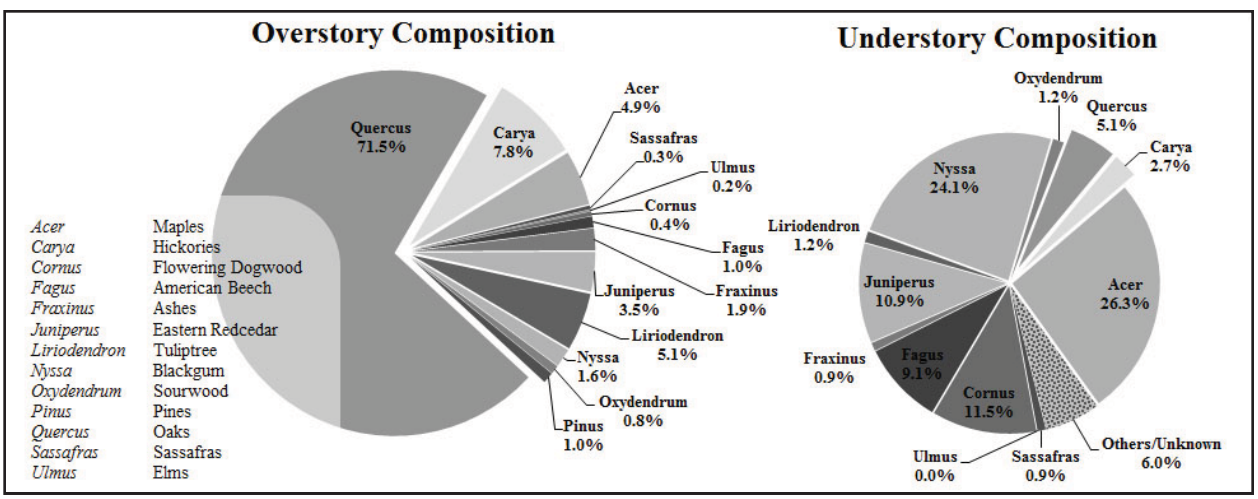

Figure 2: Tree composition of oak-hickory FMH plots. Overstory composition is based on mean BA for trees ≥ 15.0 cm at dbh. Understory composition utilizes stem density of trees ≥ 2.5 < 15.0 cm at dbh. Disproportionate compositions are remarkably apparent for three most dominant overstory species: oaks, hickories, and tuliptree (yellow poplar). Also surprising is the apparent lack of elms, a species that is generally quite common in long-unburned stands.

vines) was 7.7% before burning and 10.6% one to two growing seasons after; however, this was not found to be a significant change (N = 10, P = 0.31). None of the various plant types had a significant change after a prescribed fire with the exception of graminoids (N = 10, P = 0.03). Average pre-burn graminoid cover was only 0.008%; six plots did not contain any grass along the transect before prescribed fire. One to two growing seasons after a single prescribed fire, graminoid cover had increased to 5.2%.

Litter, Duff, and Woody Debris

The mean duff depth was 0.7 inches prior to burning, and 0.6 inches after one and two prescribed fires. While the mean duff load differed from 6.3 to 5.2 tons/acre, this difference was not found to be a significant change from pre-burn levels (N = 12, P = 0.15). The average litter depth was reduced from 1.2 inches to 0.5 and 0.3 inches after one and two fires, respectively (N = 12, P = 0.01; N = 2, P = 0.03). After a single prescribed fire the litter load was significantly reduced from approximately 2.7 to 1.5 tons acre^{-1} (N = 12, P = 0.01), an average reduction of 40%. A second burn again reduced to the litter load from 1.3 to 0.7 tons/acre, an average reduction of 77% when compared to levels measured immediately prior to the second treatment (N = 2, P = 0.03). Neither fine woody debris nor coarse woody debris was significantly changed from pre-burn levels (N = 12, P = 0.51; N = 12, P = 0.99; Figure 4). However, when all measured fuel loads are totaled, there is a significant change after the first burn (N = 12, P = 0.01). Mean total fuel loads were 15.5 tons/acre prior to burning and 12.6 tons/acre after a single treatment. The average fuel reduction for the FMH plots was 18% after the first prescribed fire.

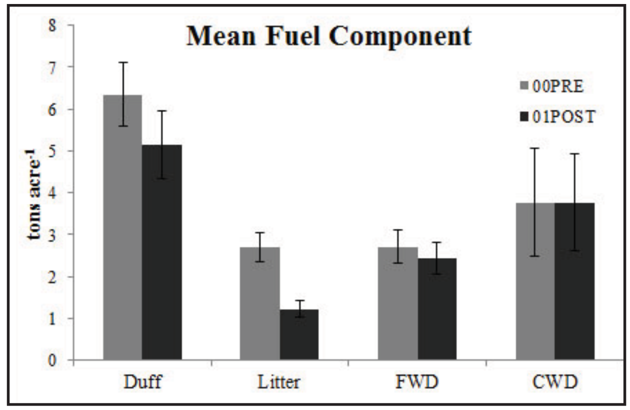

Figure 4: Changes in wildland fuels after a single prescribed fire. Total fuel load was reduced ~18%; however, as separate constituents (duff; leaf, needle, and herbaceous litter; fine woody debris (dead unattached woody stems < 3 in; FWD); and coarse woody debris (dead unattached woody stems ≥ 3 in, CWD), litter was the only significantly reduced component.

Discussion

Primary ecological goals, as stated by many of MACA's burn plans were to limit mortality of overstory trees, decrease the density of pole (understory) trees, increase native herbaceous cover, and reduce total fuel loads. Specific objectives derived from these goals are tailored for each of the various monitoring types; however, generally these goals encompass all upland oak-hickory vegetation at this park. Achieving these goals will help facilitate the restoration of woodlands at this park, while maintaining the dominance of oaks and hickories, two critically important species due to their production of hard mast for wildlife and other ecological functions.

A specific fire management objective is to limit the mortality of overstory trees to less than 20% (USDI NPS 2013). A single prescribed fire did not appear to have any impacts on the density of overstory trees. Indeed, basal area showed slight increases even as mean tree density declined, suggesting that these stands are aging and still moving through some form of successional trajectory. The vast majority of the understory is dominated by shade tolerant species (*Acer* spp., *Fagus grandifolia*, *Nyssa sylvatica*) while a very small proportion is made up of oaks, hickories, and other shade intolerant species, such as tuliptree (*Liriodendron tulipifera*). One year after a prescribed fire, there was a small reduction in understory density; however, these changes are small. This result is characteristic of other observations made in this ecosystem after only a single low-intensity fire (Brose et al. 2006). Repeated burns, within acceptable return intervals, would likely further reduce these densities allowing for shade intolerant species to be more competitive when canopy openings occur (Hutchinson et al. 2012). Tree seedling and resprout densities may not be reduced after one or two fires; however, other effects may be occurring (seedling height, etc.), allowing for noticeable changes in understory openness (Figure 5).

Figure 5: Photographic documentation of FMH plot QUMO 31. A) Photo taken fall 2000, prior to prescribed fire treatment. B) Photo taken fall 2011, two years after plot's second prescribed fire.

Remarkably, there was a large response from grasses and other graminoids from a single application of fire. Prior to burning, many of the transects did not intercept any of this group of species. Not surprising, is the delayed response of other herbaceous species. Other studies suggest that these species would increase their density and extent after further reductions in understory tree density and other abiotic factors through repeated fires (Hutchinson 2006, Royo et al. 2010). It has been well established that fires will favor grasses and other herbaceous species over woody plants (Noss 2012). The primary fine fuel in this vegetation, oak-hickory litter, can be a barrier to the germination of many plant species (Hutchinson 2006). While it was seen to be significantly reduced after a single fire, leaf litter can rapidly build back up to pre-burn levels within a few years (Stambaugh 2006). Exceptionally dense populations of white-tailed deer within the park could also confound herbaceous restoration efforts.

Long-term management of oak-hickory forests should strive to maintain fire frequencies on the landscape in order to attain more fire management goals in this broad level vegetation description. Biodiversity and conservation strategies should also strive to reestablish the complex mosaic that likely occurred in this topography (Noss 2012, Baskin et al. 1994). Managers should also investigate other seasons for burning, as burning exclusively in one season could have negative impacts on some species (i.e. spring ephemerals). Not only would endemic and unique plant species benefit from restoring fire adapted communities, but fauna, such as the diverse assemblage of bats, could benefit as well (Perry 2012). Fire management at Mammoth Cave National Park should continue to focus on restoring landscape diversity for the benefit and conservation of park's infrastructure and biota in the 21st century.

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LiDAR: A Multi-Application Management Tool

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Abstract

The amount of information contained within LiDAR is enormous as to its potential. Applications and management objectives that a single LiDAR dataset can address span everything from natural resources to fire research to archaeology. This presentation will discuss the LiDAR acquired for Mammoth Cave National Park, initial processing methods and derived products (to date). Different algorithms were deployed depending on the intent of the management objective. Natural Resources wanted to expand their polygon vegetation dataset, creating a 3-D vegetation map. Fire Management wanted to quantify the fuel loading across the park; therefore a baseline fuels map was developed. Cultural Resources wanted to identify areas with potential historic anthropogenic remnants; therefore an extensive Digital Elevation Model (DEM) was developed. When one dataset was discussed and developed, more questions were asked of the data. Tools, models, and algorithms exist, facilitating one LiDAR dataset to meet multiple management objectives.

Introduction

Remote sensing technologies have the capability to provide large amounts of information over a given spatial extent. Light detection and ranging, also known as LiDAR, is one such remote sensing technology. Although an in depth discussion of how LiDAR works is beyond the scope of this paper a brief explanation is merited. Identification of features relies on the creation of a rich dataset containing x, y and z values. LiDAR provides an ideal technology for creating such a rich dataset by creating a point cloud (each point representing a single set of x, y and z values). Unlike aerial photography however, LiDAR has the ability to pierce though the vegetation canopy as well as various stories within the canopy and beyond. LiDAR relies heavily on GPS and our understanding of the speed of light. As such, we are able to locate a platform, such as an airplane in the case of this dataset, within three dimensional space and then calculate where a pulse is returning from by using the speed of light.

Therefore the amount of information contained within LiDAR is enormous and so too is its potential. Management applications span a broad range from archaeology to natural resources to fire management. This paper discusses the LiDAR acquired for Mammoth Cave National Park, initial processing methods, derived products to date and future goals. Different algorithms were used depending on the intent of the management objective. Natural Resources wanted to improve upon existing vegetation datasets therefore a land cover classification dataset was created. Fire Management wanted to quantify the fuel loading across the park; therefore a baseline fuels map was developed. Cultural Resources wanted to identify areas with potential historic anthropogenic remnants; therefore an extensive Digital Elevation Model (DEM) was developed.

Data

The LiDAR data was funded by the Joint Fire Science Program and acquired from Mammoth Cave National Park via North Carolina State University. It consisted of derived point data and orthorectified aerial photos. LAStools was used to extract information about this dataset. Data was classified into four classes: unclassified, ground, high vegetation and low point (noise). Data was obtained on December 4, 2010 thereby reducing interference from the forest canopy. Ancillary data in the form of park boundaries, soil, geology, vegetation, and hazards was retrieved via Mammoth Cave National Park and the Kentucky GIS Clearinghouse.

Processing Methods

In order to process the LiDAR data a variety of software was employed and compared in order to determine their capabilities. As noted above, the point cloud had already been classified, but another classification algorithm, by Evans and Hudak called MCC-LIDAR, was also run on the point cloud. This was useful for two primary reasons. First, this allowed for comparison between two different algorithms. Second, proprietary algorithms are generally not fully disclosed which means that research might be conducted with little to no understanding of the classification method used. By comparing the proprietary results obtained from using Toolbox for LiDAR Data Filtering and Forest Studies (Tiffs) and open source results from MCC-LIDAR, a sense of the capabilities of each algorithm could be ascertained. This being said, the results obtained from Tiffs were much more useful due to the relative lack of noise, in the form of pocking, which was evident in the MCC-LIDAR DEM.

Derived Products

Thus far there have been three sets of products derived from the data including a fuel loading database, downed trees map, land classification map and detailed DEM. A fuel loading database was created from downed logs found within the LiDAR data. Land classification was done through combining many variants of the LiDAR data to other imagery data allowing for a highly detailed heterogeneous map. In addition, a highly detailed DEM selected from different surfaces generated using various algorithms. As a result, this highly detailed DEM allowed for archaeological prospection and the identification of potential areas of interest for cultural resource managers.

Future Goals

In the near future we hope to expand our primary applications to the dataset for the rest of the park and collaborate on other applications.

Correlating NO_x levels at Mammoth Cave National Park with Solar Irradiance

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Abstract
The nitrogen oxides (NO and NO_2, collectively known as NO_x) are among the major air pollutants monitored because of the risks they pose to human health and as indirect contributors to global climate change (Domine and Shepson 2002). They are ubiquitous products of combustion engines and other industrial processes, and are therefore typically considered to arise from anthropogenic sources, particularly at urban centers (NO_2 is responsible for the orange smog seen over certain cities during and following rush hour traffic). However, many recent observational research missions have shown a clear correlation between aqueous nitrate ion content in marine and alpine snowpack environments with the levels of NO_2, NO, and ozone (O_3) present in those areas (Dassau et al 2002, Honrath et al 1999, Helmig 2009). Subsequent laboratory studies (Honrath 2000, Bock and Jacobi 2010) have indicated that the photolysis (reaction with UV radiation, such as sunlight) of aqueous NO_3^- produces these gases through a complex network of reactions, a small subset of which are shown in Figure 1. This indicates that atmospheric models, particularly for predicting more pristine environments

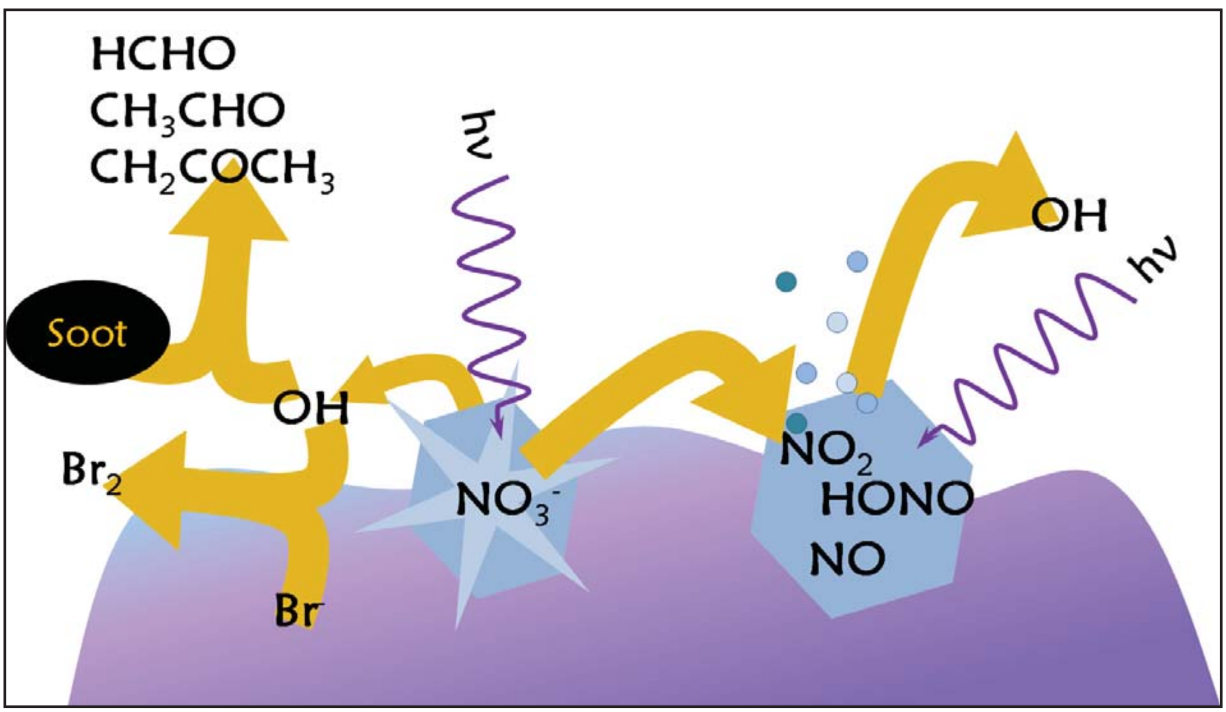

Figure 1: A small subset of the many possible reactions in wet environments at the Earth's surface following the photolysis of nitrate ion (NO_3^-). Radicals like OH and HONO play an important role, but can be difficult to monitor directly because they are highly reactive. NO, NO_2, and O_3 are all monitored at MCNP.

such as at Mammoth Cave National Park (MCNP), will need to account for this natural source of NO_x and O_3. Because the park is far from major snowfall areas and is not near any marine sources, studies done here can focus on the impact of nitrate in vegetation and soil sources, or from remnant precipitation, all of which are then exposed to sunlight.

The atmospheric monitoring station at Mammoth Cave National Park constantly monitors tropospheric levels of nitrogen oxides, ozone, and other gases, while also logging weather and particulate matter records. Because recent work by other investigators has indicated that nitrate photolysis is a major source of nitrogen oxides and ozone in the troposphere, we are mining the available data for correlations of these compounds with solar irradiance, precipitation, wind direction, and particulate matter. Although a weak correlation is found overall, strong correlations are found over the course of many single days between solar irradiance and NO_x levels. Two notable examples are seen in Figure 2. In each plot, total NO_x levels are plotted as a function of solar irradiance, but on a double logarithmic scale. In some cases, short-lived events may increase observed NO_x levels in a way that is not consistent with a solar-irradiance effect. The correlation constants are, for certain days, extremely high, while for others, the slope changes drastically at specific times, leading to a reduced correlation. Moving forward, our work will seek days following snowfall, where snow is still available on the ground, but solar irradiance is high. An increased NO_x production on such days will be further evidence that nitrate ion photolysis is a

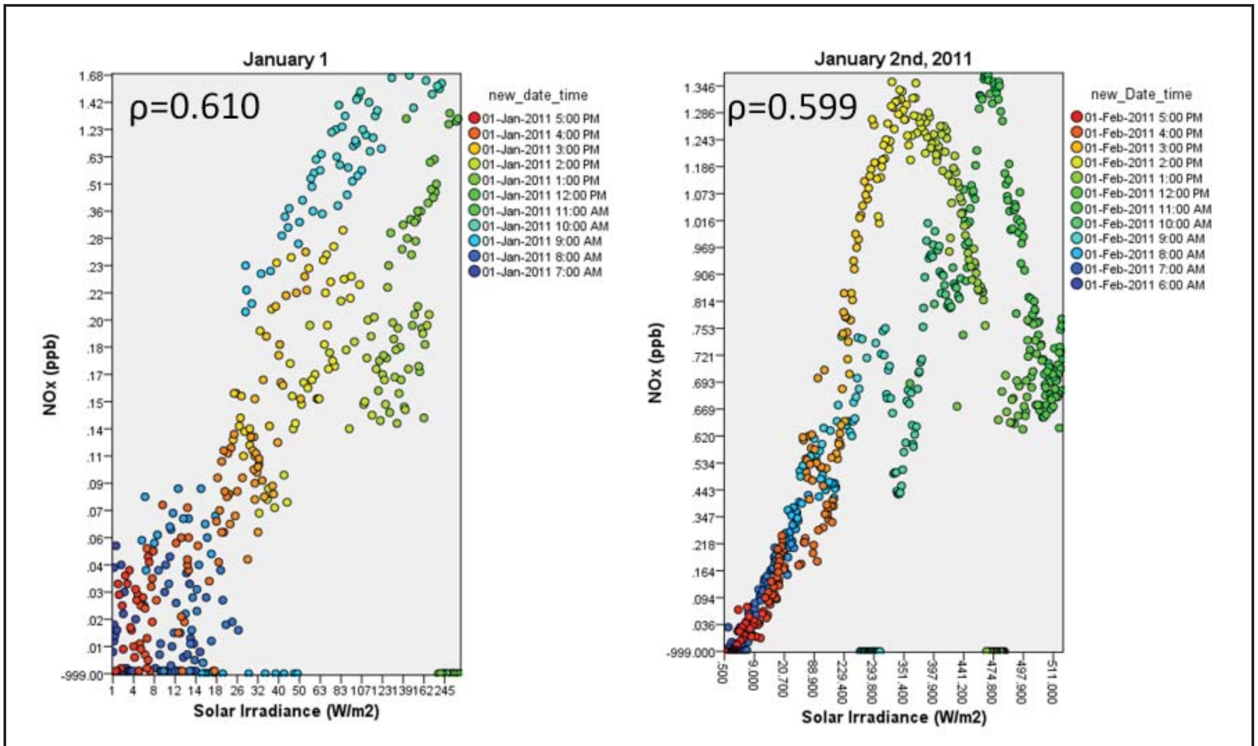

Figure 2: NO_x levels as a function of solar irradiance (log-log scale) for two different days in January of 2011. On the left, the relationship between NO_x and solar irradiance is relatively consistent. On the right, a single event drives NO_x levels high temporarily.

major source of NO and NO_2, but will also help to determine the extent to which the snow itself is responsible for the changes seen by other investigators. By identifying the extent to which nitrate photolysis is connected to precipitation and light cycles, we improve our ability to monitor large-scale changes to climate due to NO_x levels, and we are better able to separate natural and anthropogenic sources of these pollutants.

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Mammoth Cave National Park NPScape

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Abstract

NPScape is designed to address questions related to resource conservation Vulnerability and Opportunity. These dynamics are shaped at the landscape scale by three major factors: Natural Systems, Human Drivers, and Conservation Context. Consider by way of example a focal resource occurring inside a park. That resource is capable of persisting in part because of the ecological attributes of the larger natural system within which it exists. However, the value of the natural system with respect to the focal resource can be challenged by human-mediated drivers of landscape change. Precisely how these drivers interact with the natural system to impact the resource and, by extension, resource conservation vulnerability and opportunity, depends further on the stewardship of all management units within the natural system. NPScape quantifies these components and provides a suite of products to assist resource managers, planners, and interpreters.

At its core, NPScape delivers a suite of metrics that are considered integral to understanding natural resource conservation in a landscape context. Current NPScape metrics fall into six major measure categories (population, housing, roads, land cover, pattern, and conservation status) that broadly address the human drivers, natural systems, and conservation context of national parks and other neighboring lands.

Water Quality Monitoring at Mammoth Cave National Park

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Abstract
Since the main objective of the monitoring program for Cumberland Piedmont Network (CUPN) is to detect, and understand changes in major ecosystem resources, the poster information will show results of what has occurred with water quality in the park since 2004. The data cover 13 sites, sampled once a month for 2 years on and 5 years off. The main parameters monitored for MACA include: air and water temperature, pH, flow, dissolved oxygen, specific conductivity, *E. Coli*, nitrates and turbidity. The data are compiled and analyzed at the end of every sampling cycle ultimately for addressing park management needs.

Partners in Water Quality Monitoring at Mammoth Cave National Park, Kentucky

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Abstract

Water resources are essential to landscape development and maintenance of the extraordinary ecosystem at Mammoth Cave National Park, Kentucky. The National Park Service has implemented many policies and management practices in an effort to maintain and improve the water quality in the park. As part of their resources management, the Park evaluates current hydrologic conditions, as well as, anticipates and responds to emerging issues. With regards to that goal, Mammoth Cave National Park Service partnered with Tennessee State University, the Mammoth Cave International Center for Science and Learning, and the U.S. Geological Survey on a series of water-related projects from 2007-2013. The objective of this paper is to highlight some of the findings and lessons learned from the past 6 years. Many of the results presented in this paper have been presented at other conferences or published in other reports. Collaborative projects included storm-water runoff from parking lots and roads, evaluating storm-water filters, and transport of chemicals in the caves. These projects purposefully engaged students to provide professional experience and educational outreach opportunities. Over 50 student presentations related to these monitoring activities have been made at regional and national conferences in the past 6 years, resulting in numerous awards and publications. Major funding or in-kind services were provided by the partnering agencies and institutions. Additional funding for supplies and student support was provided by the National Science Foundation (Opportunity for Enhancing Diversity in Geoscience, 2007-8; Undergraduate Research and Mentoring, 2009-13), and, the Department of Energy (Massey Chair – NNSA, 2007-13). The following summaries are excerpts from previously published student papers (West et al., 2010; Diehl et al., 2012, Embry, et al., 2012, West et al., 2012).

Evaluating parking lot storm-water filters

There were two phases to the parking lot filter evaluation. The first evaluation took place seven years after the filters had been installed, prior to and after servicing the filter systems. The second phase occurred two years later, pre- and post-maintenance.

The parking lot storm filter systems use an oil and grit separator followed by filters filled with cartridges containing zeolite-perlite-activated carbon granules. The filter systems vary in size, depending on the size of the parking lots. The filters are designed to trap suspended particles and dissolved constituents, such as metals and oils, as runoff flows through the filter units. The manufacturer suggests swapping filter cartridges every 2 years (Figure 1).

The first phase project (West, et al., 2010) was conducted to determine if leaf-pack filter-systems attenuated storm runoff at seven parking lots in Mammoth Cave National Park. Grab samples were collected at the inlet and outlet of the filter systems, and analyzed for oil and grease, sediments, turbidity, gasoline compounds, nitrate,

Figure 1: Contractors serviced the storm-water filters by swapping the cartridges. (Hotel-east shown here)

ammonia, fecal bacteria, dissolved iron, and chemical oxygen demand (Figure 2). For the first sampling round, the filters had not been serviced for 8 years and did very little to remove contaminants. The contaminant concentrations at the outlet were similar to those at the inlet, with the exception of removing 20-70 percent of the oil and grease. After replacing the cartridge filters and cleaning debris out of the oil-grit separators, the re-conditioned filters did little to remove copper and ammonia from runoff waters. However, the re-conditioned filters removed up-to 99% of the benzene, toluene, ethyl-benzene and xylene, and, up to 90% of the turbidity, E. coli, Chemical Oxygen Demand and iron from the storm runoff. These results indicate that well-maintained filtration systems are more effective than clogged filters at removing many but not all contaminants from parking lot runoff.

The second phase (Diehl, et al., 2012) evaluated storm-water filters that had been serviced 2 years prior. The study focused on the first runoff waters during the storms (Figure 3). The filters were effective at removing petroleum aromatic ring compounds, but were less effective at removing zinc and copper. Regression analysis established a correlation between decreasing filter efficiency for copper with increasing parking lot size. Also, there was a positive correlation between increasing parking lot size and increasing copper concentration in the runoff. Quaternary ammonia compounds (QACs) are a new concern because of their use in White Nose Syndrome disinfection stations and in RV sanitation tanks. The filters that received the highest QAC concentrations during storm runoff were effective at reducing 40-90% of the QAC concentrations. Additional work is continuing to determine if new cartridge filters improve the efficacy of the storm-water filter systems.

Transport of Chemicals into the caves (West, et al., 2012, Embry et al., 2012)

In 2011, the National Park Service began deliberations concerning the application

Figure 2: TSU students prepared water samples and ran chemical analyses.

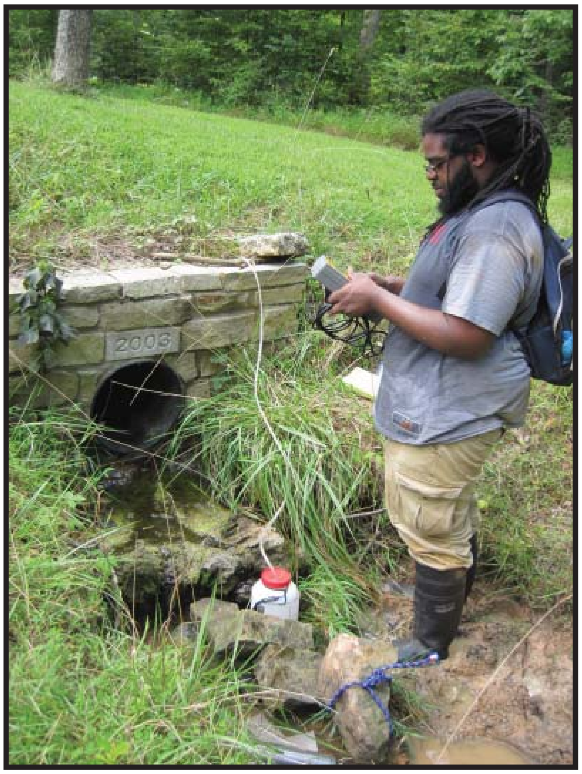

Figure 3: TSU student setting up a monitoring station at the storm-filter outlet.

of road deicers on primary roads through the Park. However, the NPS lacked some essential quantitative information with regards to contaminant transport from land surface into the cave ecosystem. The objective of this investigation was to characterize storm flow from potential source areas on the surface into the cave. The preliminary results were achieved by monitoring water chemistry and bacteria near source areas, along the surface flowpaths, and along known flowpaths in the cave (Figure 4). A quantitative tracer study found it took one hour for dye to move from land surface, along the main flowpath, and into the cave (Figure 5). Constituents, such as quaternary ammonia compounds (QACs), chemical oxygen demand, ammonia, and diesel range aromatic ring compounds, decreased exponentially along the flowpath, to below detection levels in the cave. Zinc, copper, and nitrate decreased along the surface, but then held steady at low concentrations in the cave flowpath. Phosphate and sulfate decreased along the surface flowpath, but increased slightly in the cave. This is reasonable considering there are natural sources of sulfate and phosphate in the limestone at Mammoth Cave National Park. Bacteria were cultured and evaluated for resistance to the microbicides called quaternary ammonia compounds (Figure 6). Soil-water bacteria collected near the White Nose Disinfection Stations and RV Dump Station had a much greater resistance to QACs than bacteria collected in pristine areas, indicating they are devloping antibiotic resistance. Specific conductance in flowing cave waters ranged from 200-250 uS/cm. Storms had a temporary dilution effect on specific conductance in those same cave waters. An extreme storm that showered 2 inches in 24 hours caused the conductivity to

Figure 4: TSU students installed instruments to monitor road runoff at Silent Grove.

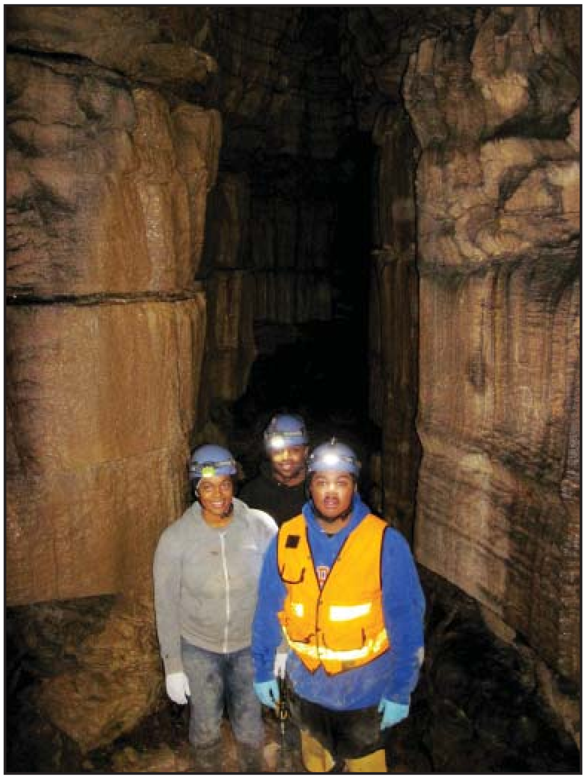

Figure 5: TSU students walked many miles in the cave to gather water samples and collect data.

Figure 6: Honors high school students helped run microbial tests on the cave samples.

drop to 40 uS/cm. A pool perched in Gratz Avenue (in the cave) had a stable specific conductance of 315-335 uS/cm regardless of storms. These preliminary results help us to understand the current conditions in the cave prior to road salt treatment and how various chemical concentrations adjust along the flowpath into the cave.

Conclusions

This partnership between Mammoth Cave National Park, U.S.G.S., Mammoth Cave International Center for Science and Learning, and, Tennessee State University to investigate water-quality in the Park had many positive outcomes. Some results were very tangible, such as, the monitoring results used to influence management decisions or document current ecosystem conditions. Results that were difficult to quantify include the benefits received by engineering and environmental students as they interacted and worked with professionals from the partnering institutions. Counting the vast number of student awards, presentations, and publications, or counting the number of internships, is one way to quantify the benefits of this project. But even that approach undervalues the results of this unique partnership. These monitoring activities helped to train the next generation of scientists and engineers and provided a very positive experience for all the participants.

Acknowledgement

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(all photos by T. Byl and R. Toomey)

Multiple Storm Event Impacts on Epikarst Storage and Transport of Organic Soil Amendments in South-central Kentucky

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Abstract
The groundwater in agricultural karst areas, such as Kentucky's Pennyroyal Plateau, is susceptible to contamination from organic soil amendments and pesticides. During 2011, water samples and geochemical data were collected every four hours before, during, and between storm events from a waterfall in Crumps Cave from January to September to track the transport and residence time of epikarst water and organic soil amendments during variable flow conditions. Geochemical data consisting of pH, specific conductivity, temperature, and discharge were collected continuously at 10-minute intervals, along with rainfall amounts. The changes in geochemistry indicate simultaneous storage and transport of meteoric water through epikarst pathways into the cave, with rapid transport of bacteria occurring through the conduits that bypass storage. Results indicate current best management practices in agricultural karst areas need to be revisited to incorporate areas that do not have surface runoff but where contaminants are transported by seepage into local aquifers.

Three Examples of Chemical Transport in Storm Runoff at Mammoth Cave National Park, Kentucky

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Abstract
The karst landscape at Mammoth Cave National Park, Kentucky, was formed by water through the dissolution of soluble rocks forming sinkholes, disappearing streams, emerging springs, closed depressions, and a combination of wet and dry caves. The Park's cave streams and pools provide a home to unique organisms. Surface waters in the Park tend to rapidly drain into subsurface geologic features and caves. This rapid infiltration makes the subsurface vulnerable to contamination. The objective of this investigation was to characterize chemical transport from the surface into the cave. The preliminary results were achieved by tracer studies and monitoring water chemistry along known flowpaths. The results presented in this paper are the outcome of several studies occurring between 2009-2012 in a partnership between Mammoth Cave National Park, Tennessee State University, Mammoth Cave International Center for Science and Learning, and U.S. Geological Survey. Processes that influenced chemical transport included storm intensity, time between storms, epikarst saturation, dispersion, dilution, and complex flow paths in the geology.

Introduction
The ecosystem within Mammoth Cave is dependant on adequate clean water for survival. To protect the waters, the Park has addressed the intense vehicle traffic in the parking areas with storm runoff filters. However, they are still concerned about surface chemicals entering the cave ecosystem. Currently, the National Park Service, in agreement with US Fish and Wildlife and Kentucky environmental regulators, has approved the limited application of road deicers on primary roads through the Park during snow or ice storms. However, the NPS lacks some essential quantitative information with regards to salt transport from land surface into the cave ecosystem. The chemical transport mechanisms including timing, contaminant load and concentration, and hydrologic response are not fully understood. The transport of contaminants into surface water and into the cave ecosystem could adversely impact the aquatic habitat of the rare and endangered species. The objective of this project was to identify and quantify processes important to chemical transport at Mammoth Cave National Park. The approach included monitoring water quality and quantity at points along selected flow routes into the cave.

Materials and Methodology
Three sites were selected for surface and subsurface monitoring stations (Figure 1). Site 1, Silent Grove sinking creek, is

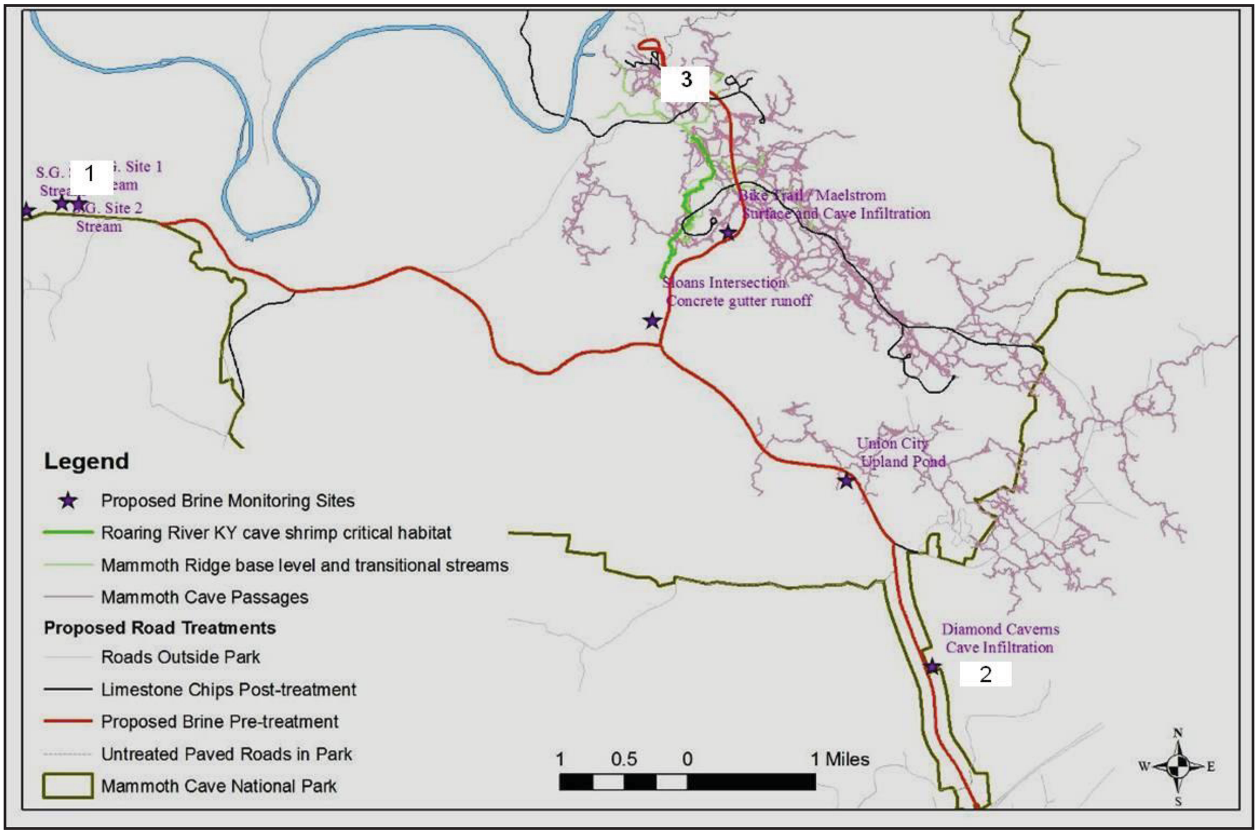

Figure 1: Three monitoring sites selected for monitoring in response to potential road brine application. 1. Silent Grove sinking stream, 2. Diamond Caverns, 3. Post Office-RV dump station. Roads and critical cave habitat are indicated on the map.

near the west edge of the Park. This site is adjacent to an off-park road that receives salt treatment during inclement weather. Site 2 was located near the south entrance to the Park coming from Interstate 65, at the private cave called Diamond Caverns. This site was selected because Diamond Cavern staff have observed rapid flow response during storms, and, the road is expected to be salted during snow events. Site 3, starts at the Post Office parking lot, which has been affiliated with quaternary ammonia compounds (Diehl, et al., 2012), and flows into the historic section of the cave.

Monitoring

YSI datasondes equipped with temperature, specific conductance, pH, dissolved oxygen, turbidity, Rhodamine-WT, and/or water depth probes were deployed along the flow paths at the monitoring sites. The sondes were serviced (calibrated, data uploaded, batteries replaced) every 2-3 weeks. Water samples were collected and analyzed for quaternary ammonia compounds (Hach, 2005) and/or chloride (Hach, 2012).

Results and Discussion

The transport of chemicals, such as salts, from the surface to the caves was studied at Mammoth Cave National Park, KY. Results from three sites are presented here. Site 1, Silent Grove sinking stream, is a road adjacent to the Park and was treated with rock-salt in the winter of 2011 and 2012. Two monitoring stations in the stream, one within 50 feet of the road and another one ~500 feet downstream, were instrumented with datasondes to monitor salt concentration in the stream. Salt spread during a cold spell was washed into the creek during a subsequent rain event. The salt concentration was diluted and dispersed as the water flowed from the road to the sink 500 feet downstream. A calibrated regression curve comparing known concentrations of salt to conductivity measures allowed us to extrapolate the chloride concentration in the stream. The highest chloride concentration was observed at the upstream site (76 mg/L). The chloride concentration was well below the action level of 600 mg/L.

Data compiled from several sites and summer storm-events were used to run correlations between specific conductance values in the first runoff and time-intervals between the storm events. We observed a weak correlation between increasing time intervals and increasing specific conductance. Although correlation does not imply cause and effect; it is reasonable to assume longer intervals between rain events allows for greater build up of potential dissolved solids.

Monitoring stations were set up at the road drainage ditch entering Diamond Caverns parking lot and in a cave pool below the tour route. A winter storm in February 2011 produced runoff that entered the cave and generated a decrease in the specific conductance of the cave pool. There was a short time period (<30 minutes) between the start of the rain and water entering the ditch. The specific conductance in the cave pool, which is an indicator of dilution, responded almost 5 hours later. This time lag was partly due to the flow path length and the head pressure needed to push water to the pool. A second wave of precipitation eight hours later evoked a conductivity response in the pool within a 2-hour time period. A third wave of rain evoked a cave-pool response in one hour. These data suggest that the response time in the cave to storms is partially a function of regolith and epikarst saturation.

A tracer study was conducted at the outfall of the Post Office parking lot storm filter (Embry, et al, 2012). This parking lot was the source of quaternary ammonia compounds (QAC) during several storms (Diehl, et al, 2012). The 175 mL of Rhodamine-WT tracer was released by storm runoff. It took approximately 1 hour and 15 minutes to travel from the discharge of the parking lot filter into Annette's Dome off Gratz Avenue. A monitoring station in the Devil's Cooling Tub at the other end of Gratz Avenue detected a smaller quantity of Rhodamine approximately 1 month and 2 days after tracer release. The average velocity of the tracer transport was estimated by dividing the relative distance from injection point (meters) by the time (minutes). The tracer traveled at an estimated speed of 3.3 meters per minute to reach Annette's Dome and Shaler's Brook. In comparison, the dye traveled at an average velocity of 0.01 meters per minute to reach the Devil's Cooling Tub. Another interesting fact was that the dye had to travel across a surface basin divide (Styx spring and Echo spring) to reach the Devil's Cooling Tub. This illustrates how complicated karst hydrology can be.

Summary

This project evaluated the transport of chemicals during storms at three locations. Data from Silent Grove sinking stream show that significant dilution and dispersion can occur within a 500-ft reach of surface stream. These dilution and dispersion processes are important factors for attenuating salt in road runoff. Additional data is being collected at other sites to determine if this pattern is applicable to other areas in the Park. Monitoring activities at Diamond Cavern area found that the response time in the cave was partially a function of epikarst saturation; the more saturated the epikarst, the quicker the response. Studies characterizing the transport from the Post Office into the cave reveal that surface chemicals can arrive in the cave in minutes or weeks after being released. Also, the tracer study illustrates how complicated karst hydrology can be when the dye moved across a surface basin divide.

Additional acknowledgements
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Evaluation of Stormwater Filters at Mammoth Cave National Park, Kentucky, 2011-12

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Abstract

Studies in the 1970s found potentially toxic levels of metals entering Mammoth Cave's underground streams through storm recharge. Additional studies confirmed that stormwater from parking lots and buildings flowed rapidly into critical cave habitats. The Park's management responded to these findings by installing storm runoff filter systems on the most heavily used parking lots in 2001. The Park entered an agreement (2010-12) with Tennessee State University, the USGS, and WKU-Mammoth Cave International Center for Science and Learning to evaluate the filter systems to determine if they were removing hazardous compounds from stormwater runoff. The objective of this study was to evaluate stormwater filters before and after replacing 2-year-old ZPG cartridge filters. The study focused on the first-flush runoff waters during the storms. The filters were not effective at removing quaternary ammonia compounds (QACs), and moderately effective at removing zinc and copper. The filters were very effective at removing diesel-range aromatic ring compounds (fuels). Regression analyses were used to evaluate trends between parking lot size and filter efficiency. The efficiency of the filters to remove fuels improved with basin size. The efficiency to remove QACs decreased with basin size. Basin size did not appear to have any correlation to zinc or copper removal efficiency. Human activity, such as construction, probably played a role in the storm-water chemistry and the efficacy of the filters to remove certain contaminants.

Introduction

Mammoth Cave in Central Kentucky has unique organisms that live in the cave waters and they are dependant upon high quality water supplied through rain recharge. Barr (1976) reported elevated metals and pollutants in the cave waters and speculated sources on the surface. Meimen and others (2001) confirmed a direct hydraulic link between certain parking-lot basins and several cave streams. The Park responded to these findings by installing storm runoff filter systems in 2001. The Park entered an agreement in 2010-12 with Tennessee State University, TN USGS, and WKU-Mammoth Cave International Center for Science and Learning to evaluate the filter systems. This report focuses on the assessment of 2-year-old filters and filters less than 1 year old. The filter maintenance included cleaning leaves and detritus from the oil-grit separator, and replacing the zeolite-perlite-granulated activated carbon (ZPG) cartridges in the main filter systems.

Materials and Methodology

Storm waters were monitored using first-flush siphon samplers (Diehl, 2008). These samplers were selected because they were small, required no power, and could catch water from the rising runoff. However, if the rain was too small to produce enough rise in the water, it would pass by the sampler. A minimum of three samples representing 3 different storms were used for interpretations. A list of chemicals, analytical methods and detection ranges are listed in Table 1.

Results and Discussion

The goal of this project was to determine if the filters were adequately removing contaminants that could harm the indigenous organisms in the cave. The initial test in 2008, on 7-year old filters, found they were ineffective at removing anything (West, et al., 2010). In this round of sampling, we evaluated the ZPG filters after being in place for 2 years; the suggested life of the filters, and within 8 months of replacing the filters. There were over 2,500 chemical data points generated over the 2011-12 study. This report is limited and summarizes results for aromatic fuel compounds, QACs, zinc and copper. These four chemicals represent water soluble chemicals that are known to be toxic to aquatic organisms.

Table 1: Chemical constituents analyzed in the first flush of the storm water.

Anaylsis included:	Method	Dectection range
Quaternary ammonia compounds (CTAB)	Hach 8337	0.2-5.0 mg/L
Chemical oxygen demand	Hach 8000	1-150 mg/L
Aromatic compounds (diesel range)	Turner Design	10-038R 0.01-10 mg/L
Ammonia (Nessler's)	Hach 8075	0.1-70 mg/L
Zinc	Hach 8009	0.02 - 3.00 mg/L
Copper (Porphyrin Method)	Hach 8143	5 - 210.0 ug/L
Nitrate	Hach 8171	0.2 - 5.0 mg/L
Phosphate (reactive, PO4^3-)	Hach 8048	0.05 - 2.50 mg/L
Sulphate (modified)	Hach 8051	0.5 - 70 mg/L
Specific conductance	YSI meters	0 - 1416 uS/cm
Hardness, Calcium (as CaCO3)	Hach titration 8204	10-4000 mg/L

Diesel-range aromatic compounds (fuel)

The ZPG filters were effective at removing dissolved aromatic compounds from the storm runoff (Figure 1a). The Woodland Cottage filter received the highest average concentration of fuel in 2010, but was able to remove over 90%. The Visitor Center (which was inaccessible during the 2011 sampling period due to the Visitor Center construction), was the only filter system ineffective at removing aromatic compounds. This was probably due to sediments carried in during construction runoff that blocked the binding sites on the activated carbon. The efficiency of the filters to remove aromatic fuel compounds increased with increasing parking lot size (Figure 1b). This apparent improvement in filter efficiency was possibly a function of the filters strong performance despite more fuel being released by the greater number of cars.

Zinc and Copper

The filters did little to remove zinc from the storm water (Figure 2a). In some cases, the average zinc concentration coming out of the filter unit was higher than the zinc concentration entering the filter. However, the average concentrations of zinc going in and coming out of all the filter systems were less than 0.5 mg/L. This is probably a safe concentration for the aquatic organisms, given the short exposure time during storm runoff and the antagonistic effect of calcium on zinc toxicity (Borgmann, et al., 2005). The efficiency of the zinc-removal

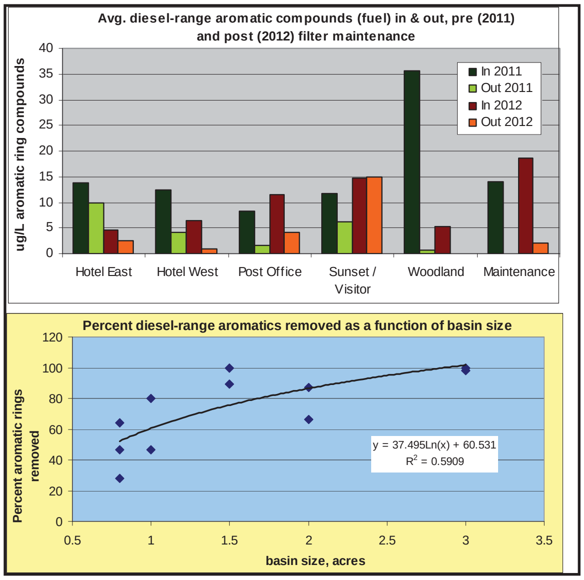

Figure 1: 1a(top graph): Average concentration of diesel range aromatic compounds dissolved in storm runoff at the filter inlets and outlets prior to and after the filters had been serviced in the late fall of 2011. [Sunset / Visitors is Sunset Lodge in 2011, and, Visitor Center in 2012; n = 3 or more] 4b (bottom graph): Regression analysis comparing the percent aromatic compounds removed by the filter as a function of parking lot size.

process was not affected by the size of the parking lot (Figure 2b). The regression shows a slight increase in efficiency with increasing lot size, but the R-square (0.08) indicates this was not a good fit with the data.

Prior to maintenance in 2011, the ability of the filters to sequester copper from the storm water was inconsistent (Figure 3a). After the filters were serviced in late 2011, the filters reliably removed greater than 50% of the copper, with the exception of the Visitor Center filter system. As noted before, the Visitor Center filter received storm runoff rich in suspended sediments after being serviced, rendering it less effective. The plot comparing filter efficiency to parking lot size illustrates there was no correlation between copper removing ability and parking lot size (Figure 3b)

Quaternary ammonia compounds
The storm filters appear to do very little to reduce QACs in the storm runoff, with the exception of the Post Office filter prior to servicing it (Figure 4a). QACs are known to adsorb to particles, especially organic particles. The cartridges and holding tank were rich in organic particles from leaf detritus prior to being serviced. The new ZPG filters were not designed to remove emulsifying compounds like QAC. The filters do tend to lower the QAC concentration, but they let approximately 50% pass through in the first flush.

When all the data were plotted comparing filter efficiency with parking lot size, there appears to be no correlation (Figure 4b).

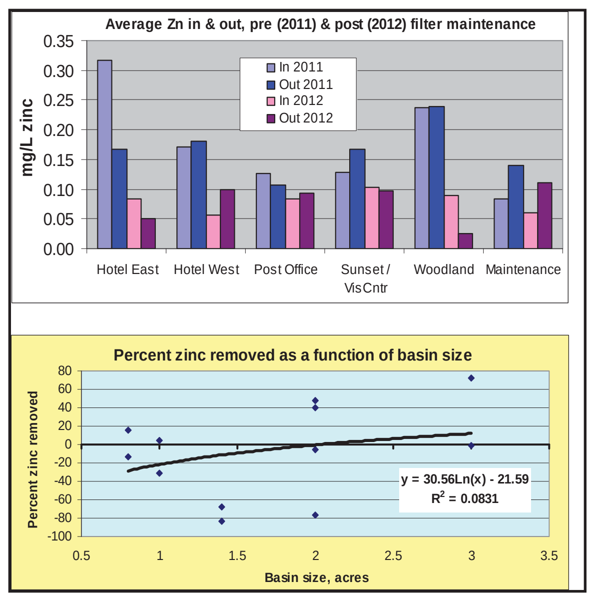

Figure 2: 2a (top graph): Average concentration of zinc (Zn^{2+}) dissolved in storm runoff at the filter inlets and outlets prior to and after the filters had been serviced in the late fall of 2011. [Sunset / Visitor bars are for Sunset Lodge in 2011, and, Visitors Center in 2012; n = 3 or more]. 2b (bottom graph): Regression analysis comparing the percent zinc removed by the filter as a function of parking lot size.

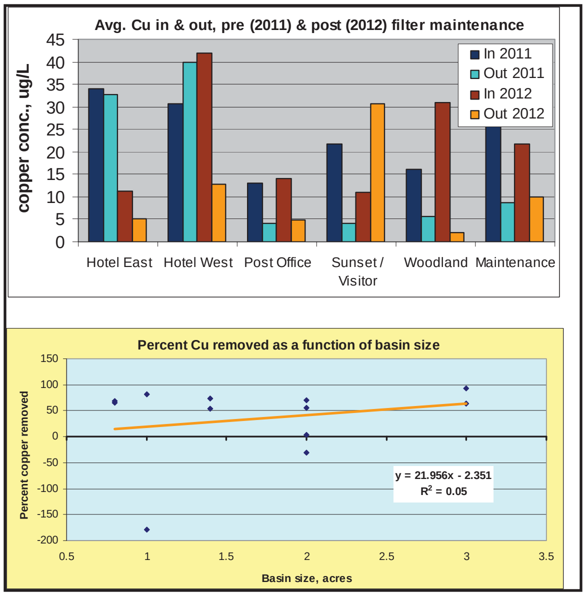

Figure 3: 3a (top graph): Average concentration of copper (Cu^{2+}) dissolved in storm runoff at the filter inlets and outlets prior to and after the filters had been serviced in the late fall of 2011. [Sunset / Visitor bars are for Sunset Lodge in 2011, and, Visitors Center in 2012; n = 3 or more]. 3b (bottom graph): Regression analysis comparing the percent copper removed by the filter as a function of parking lot size.

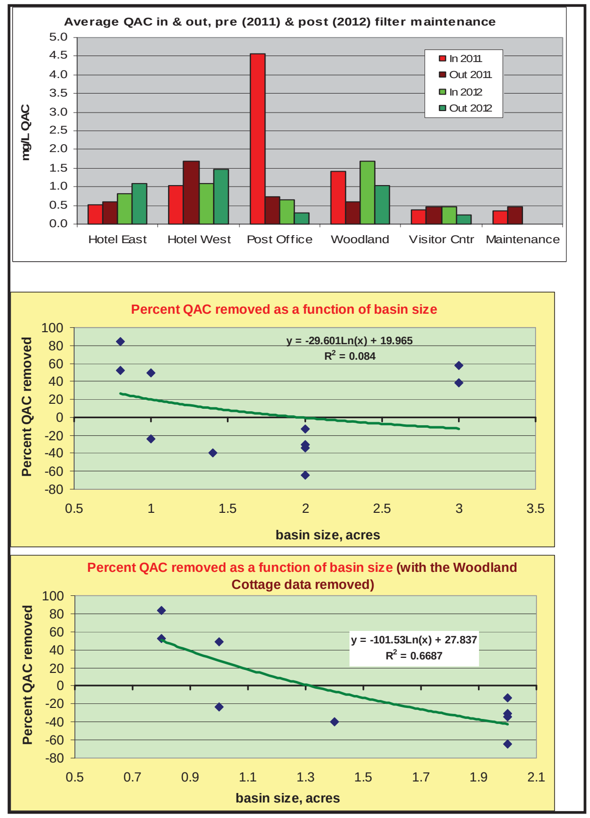

Figure 4: 4a (top graph): Average concentration of quaternary ammonia compounds dissolved in storm runoff at the filter inlets and outlets prior to and after the filters had been serviced in the late fall of 2011. [Sunset / Visitor bars are for Sunset Lodge in 2011, and, Visitors Center in 2012; n = 3 or more]. 4b (middle graph): Regression analysis using the data from all the parking lots comparing the percent QAC removed by the filter as a function of parking lot size. 4c (bottom graph): Regression analysis dropping the data from the largest parking lot, Woodland Cottage, comparing the percent QAC removed by the filter as a function of parking lot size.

However, if we remove the largest parking lot (Woodland Cottage) from the plot (Figure 4c), we get a good correlation. This correlation reveals that the larger the parking lot, the less efficient the filter systems are at removing QACs from storm runoff. This may be due to the shorter residence time in filters receiving waters from larger lots. Ho demonstrates in lab sorption experiments that sorption of QAC by the ZPG filters is dependent on time (2013, these proceedings).

Summary

This project evaluated the efficiency of the parking lot storm filters to remove various chemicals. The filters did an excellent job removing fuel compounds. They did a moderate job removing copper from the runoff, but were inconsistent at removing zinc and QACs from storm water.

Additional acknowledgements

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Use of Sorption Isotherms to Improve the Efficacy of the Storm-water Filters

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Abstract

Sorption has been widely used as an inexpensive and environmental friendly water treatment technology. A large variety of adsorbents with different adsorption mechanisms have drawn interests, and combinations of adsorbents will enhance sorption of mixed solutions. However, current sorption research tends to focus on single material. The objective of this study was to develop sorption isotherms for ZPG®, (Zeolite, Perlite, Granular Activated Carbon), used in a stormwater filter cartridge. Contaminants of concern include Cu^{2+} and quaternary ammonia compounds (QAC). Adsorption isotherms were established for Cu^{2+} and QAC, and the best fit for the isotherm data was a Langmuir isotherm for Cu^{2+} and Freundlich isotherm for QAC. The Empirical Constant for Cu^{2+}, Qo, which represents the maximum adsorption capacity, was 4.61μg/L. The equilibrium constant K, which represents the distribution of the contaminants between water and ZPG particles, was 11μg/g for Cu^{2+} and 8μg/g for QAC. The adsorption isotherm, adsorption rate, and maximum adsorption capacity are used as the criteria, and the result can be used for performance evaluation with the safety limits for the aquatic organisms presented in the Mammoth Cave National Park.

Background and Criteria

Mammoth Cave National Park is home to the world's longest cave and one of the most diverse cave biological communities in the world. With approximately 400,000 annual visitors, stormwater filters are used in the parking lot areas to prevent anthropogenic contaminants from entering into cave and groundwater. This is done to protect the aquatic habitat of rare and endangered species. However, field data have shown that the performance of the stormwater filters fluctuates. Toxic contaminants with concentrations higher than chronic effects level are sometimes found at the filter effluent. Two major contaminants are considered in this study, copper (Cu^{2+}) and Quaternary Ammonium Compounds (QAC).

Copper is a common contaminant found in vehicles, tires, and especially from parking lot runoff. Field concentration of Copper(II) ion is found to be between 2.8 to 92.0 μg/L. Cave fish, and aquatic invertebrates such as isopods and amphipods are vulnerable to copper (Dobbs, et al, 1994; Rayburn et al., 2003). Copper toxicity to aquatic organisms is due to binding to gill membranes and causing damage, and it interferes with osmo-regulatory processes. Chronic limits of copper for aquatic organisms range from 2.5 to 104μg/L.

High concentration of Lysol® Disinfectant Cleaner is used in the park to reduce risk of transferring *Geomyces destructans* spores, which is the cause of White Nose Syndrome, a disease that has threatened North America's bat population. Quaternary Ammonium Compounds (QAC) are one of the major chemicals in Lysol® , and they are toxic to fishes and aquatic invertebrates (Tezel, 2009).

Figure 1: ZPG cartridges in filter system.

The objective of this project was to determine the adsorption isotherm, and adsorption rate of ZPG®. A second goal was to evaluate the effectiveness of the treatment media. The scope of the project included lab studies with some field validation.

Materials and Methodology

The filters used a zeolite-perlite-activated carbon granules (ZPG®) to sorb dissolved contaminants in the sotrm runoff. The ZPG used in the isotherm studies was provided by Mammoth Cave facilities management from the Stormwater Management StormFilter® used by the Park. Each constituent in the ZPG media has different properties, and a combination of media provide a more effective configuration than single media, and meet a wide range of treatment goals (Table 1).

The batch method was used to establish sorption isotherms. Batches were set up with 20g of ZPG® filter media and different concentrations. Composition of each media in volume was about 50% Zeolite, 40% Perlite, and 10% GAC. The bottles containing the ZPG and solution waters were put into a shaker at 25°C, and rotated at 125 rpm for known lengths of time. Initial concentrations of Cu2+ or QAC were measured. The amount remaining in solution were measured at various time periods. The copper concentration was measured using the Hach Porphyrin method (Hach, 2005). The QAC concentrations were analyzed using the Hach direct binary complex method and measured on a spectrophotometer (Hach, 2005).

Results and Discussion

Adsorption of Copper

Results of the copper studies are shown in Figures 2 through 4.

Table 1: Summary of ZPG constituents' properties.

Constituent	Properties
Zeolite	used in the water filter. Clinoptilolite ($Na_{7.3}Si_{29}Al_7O_{72}•23.9H_2O$), a sodium rich zeolites. The enrichment of sodium and the small pore size provide the clinoptilolite high cation exchange capacity (CEC). Cations of heavy metals such as zinc, copper, and lead are removed from water by displacement of light metal cations, Na^+, in the zeolite matrix.
Perlite	pretreated Expanded Perlite, EP, is used in the water filter. It is mainly composed of Silicon dioxide, SiO_2, and Aluminum Oxide Al_2O. EP has high porosity, low density, high surface area, and inert chemical property, which give EP excellent ability to trap sediments and adsorb oil and organic pollutants
Granular Activated Carbon	is one of the most widely used materials to remove organic contaminants from water through adsorption. It has an extensive internal surface area with high porosity and high carbon content which provides high adsorption capacity.

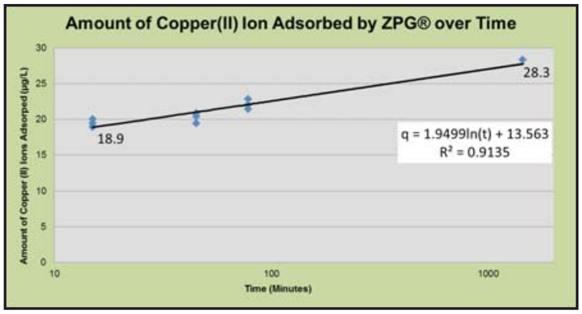

Figure 2: Initial concentration of 40µg/L of Copper(II) ion is used to determine the amount of Cu^{2+} adsorbed to ZPG®. The nature logarithm curve indicates that the adsorption rate decreases over time, dq/dt = 1.95/t.

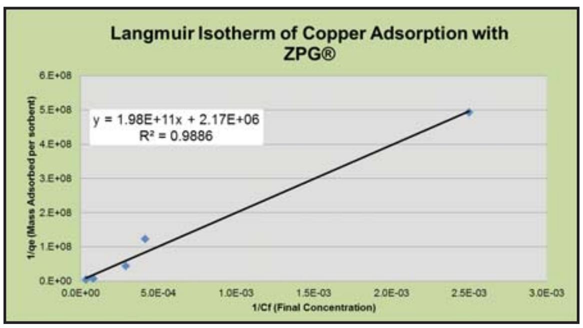

Figure 3: Langmuir isotherm is found to best describe the Cu^{2+} adsortion process onto ZPG®, Physisorption and chemisorption are both expected to contribute in the treatment process. Equilibrium oncentration of Cu^{2+} in solution, C_e, is 4.61µg/L. The adsorption capacity of ZPG®, K_d is 11µg/g. The relationship between the adsorbed Cu concentration and Cu concentration in solution can be described by the equation, q = 5.06 x 10^{-12} C / 1 + 1.10 x 10^{-5} C.

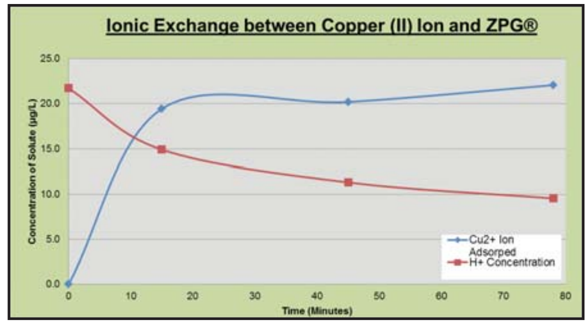

Figure 4: Langmuir isotherms indicate that chemisorption occurs, ionic exchange is expected between the dissolved Cu ion and sodium ion in zeolite. The exchange process can be determined by the change in pH value. An increase in pH value is found during the adsorption process. It agrees with the assumption that ionic exchange occurs. The increase in pH is due to the dissolution of sodium ion and the formation of NaOH, which is indicated by the decrease in H^+ concentration. The adsorption process seems to be a fast process in which the process slows down after a rapid increase in Cu^{2+} ion adsorbed in the first 15 minutes. Hydrogen concentration also slows down after about 45 minutes.

Adsorption of QAC

Results of the QAC sorption isotherm tests are shown in Figures 5 and 6.

Summary

The sorption of Cu^{2+} from water by ZPG® is best described by the Langmuir isotherm. The Freundlich Isotherm best describes the QAC sorption to ZPG®. The maximum sorption rate, which reduced the QAC concentration in half, was reached in about 15minutes; however, adsorption rate rapidly decreased afterward. The bottom line of these results indicates that when the contaminant concentration is high in the rain water, it will not be treated effectively in a short period of time, and may be released out the discharge effluent pipe.

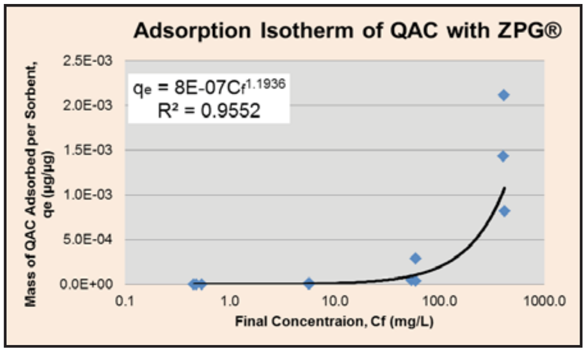

Figure 5: Freundlich isotherm is found to best describe the QAC adsorption process onto ZPG®. Chemisorption is negligible because QAC does not dissolve in water, and no ionic exchanged is expected. Physisorption is expected be the major contributing process in treatment. Granular Activated Carbon and Perlite are the major contributors in the adsorption process. The adsorption capacity of QAC onto ZPG®, Kd is 0.8µg/g. The relationship between the adsorbed QAC concentration and QAC concentration in solution can be described by the equation, $q_e = 8 \times 10^{-7} C_f^{1.1936}$.

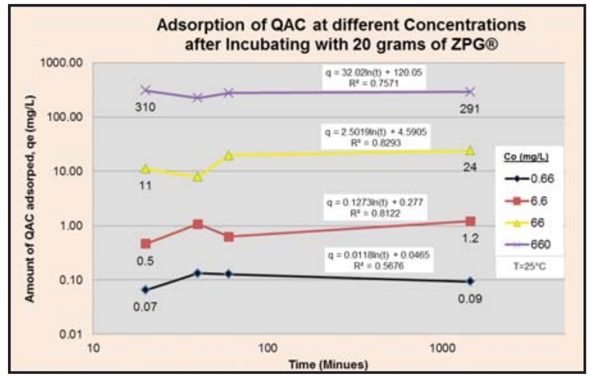

Figure 6: The amount of QAC adsorbed over time with different concentrations was compared. The process is best described by natural logarithm which means the rate of change of QAC adsorbed decreases over time. Also, the adsorption rate is higher with higher initial concentration. The difference in adsorption rate is due to the diffusion effect. The higher concentration of QAC has higher possibility to be adsorbed onto the filter media.

Additional acknowledgements
The authors wish to thank Steve Kovar, MACA NPS Chief of Facilities Management; Bobby Carson, MACA Chief of Science & Resources Management; Eddie Wells, MACA Volunteer Coordinator; Shannon Trimboli, Mammoth Cave International Center for Science and Learning; Dr. Malkani, Assistant Dean, TSU College of Engineering, for resources and support.

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Improvements to the RV Waste-transfer Station Design to Reduce Contaminated Storm Runoff

David Solomon[1], Sean McMillan[1], Ashley West[1], and Lonnie Sharpe[1], Acknowledgement - Thomas Byl[1,2]

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Abstract

Mammoth Cave in Central Kentucky is the world's longest cave system and has been designated an international biosphere. It has unique organisms that live in the cave system and they are dependant upon high quality water supplied through rain recharge. We have documented quaternary ammonia compounds (QAC) levels ranging from 0.2 to 22 mg/L in storm flow, as well as, other chemicals coming from the RV waste-transfer station. The objective of this project was to re-design the drain system around the dump station to prevent spillage from washing down into the cave. The first design feature is a v-trench to catch storm runoff and redirect it into the sanitary sewer. The second feature is a gently elevated barrier that will impede the flow of runoff from the impacted area. The designs presented in this paper incorporate both features.

Background

Mammoth Cave National Park in Central Kentucky has been designated as an international biosphere. Approximately 400 miles have been mapped and explored in Mammoth Cave. The National Park Service encourages campers and tourists to visit the park, while balancing that with protecting the ecosystem above and below ground. The cave system was formed by erosion and dissolution of limestone by the groundwater over hundreds of thousands of years. Water still plays an important role in today's cave, especially the high quality water needed to sustain the unique ecosystem in the cave.

Tennessee State University, Mammoth Cave International Center for Science and Learning, the U.S. Geological Survey and Mammoth Cave partnered to monitor water quality in areas of the Park with high visitor traffic. Those water-quality monitoring activities identified a new source of contaminants. Quaternary ammonia compounds (QACs) spilled at the recreational vehicle (RV) waste-transfer station were washing into the storm drain. The storm-water filter system receiving this runoff was not very effective at removing all the contaminants and QACs were making their way into the cave system during storm runoff. The objective of this project was to design a modification to the RV waste-transfer area to prevent the release of QAC since the filter system is inadequate. This issue must be resolved by re-designing the drainage area adjacent to the RV dump station.

Materials and Methodology

QACs

Storm monitoring was conducted to determine water quality of parking lot storm runoff and how effective the storm-filters were at reducing pollutants (McMillan, et al., 2013). These activities included catching first-flush storm runoff and analyzing for QACs at several parking lots. The runoff from the Post Office parking lot was surprisingly high in QACs during the summer, ranging from 0.2 to 22 mg/L QAC.

Storm runoff

Storm flow patterns in the Post Office parking lot were observed during several rainstorms. It was apparent that on the south side of the building, water flowed from the front of the building, down through the RV waste-transfer area, and into the storm drains to the filter (Figure 1). The filter released the storm water out the discharge pipe, and down the hillside to a sinkhole. The water would sink at the sandstone-limestone contact, and enter cave system at Annette's Dome. This process would take approximately 1 hour and 15 minutes (Painter, et al., 2013).

RV Waste-transfer station

The engineering design drawings, along with measurements taken at the RV waste-transfer station, were used to re-design the drain area. Some design constraints included minimizing disruption to the parking lot, holding down costs, limiting the flow of non-QAC storm runoff water into the sanitary sewer (i.e., storm runoff from areas away from the RV waste station should be directed to the storm filter), keeping the station user-friendly, and preventing the release of QAC and other RV wastes into the storm-filter. CAD was used to visualize the design.

Figure 1: Storm-water drains from the Post Office parking lot and mixes with spilled waste residue, rich in QAC, at the RV disposal station. It carries the QAC into the storm filter, down the ravine, and into Annette's Dome (Cave level B). This drain area needs to be re-designed to prevent chemicals from getting into the cave.

Results and Discussion

QACs

The average summer concentration of quaternary ammonia compounds, starting at the Post Office parking lot (RV dump station), decreases as it flows through the filter system and into the cave (Figure 2). However, the concentration in the cave is higher than desired. The regression shows the reduction in QAC along the flow path.

Storm runoff

The most efficient design option to prevent the transport of spilled QACs in storm runoff is to prevent stormwater from washing through the disposal area. That is, prevent the waters from the other parts of the parking lot from flowing through the RV waste-transfer area. Concurrent with that, waste-waters that do spill in the RV transfer area should be contained and directed to the sanitary sewer. These flow changes could be accomplished using low berms and trenches in the vicinity of the RV waste-transfer station.

RV Waste-transfer station

A berm, similar to a low speed bump, would be placed on the up-gradient side of the disposal station. Inside that berm would be a V-trench drain to catch any water and direct it to the sanitary sewer. Figure 3 shows a CAD drawing oriented from upgradient to down-gradient, the direction of storm runoff flow. Storm runoff from the upper part of the parking lot would be deflected by the berm so that it wouldn't run through the waste-transfer station or get caught by v-trench. The berm does not need to encircle the entire station, but only

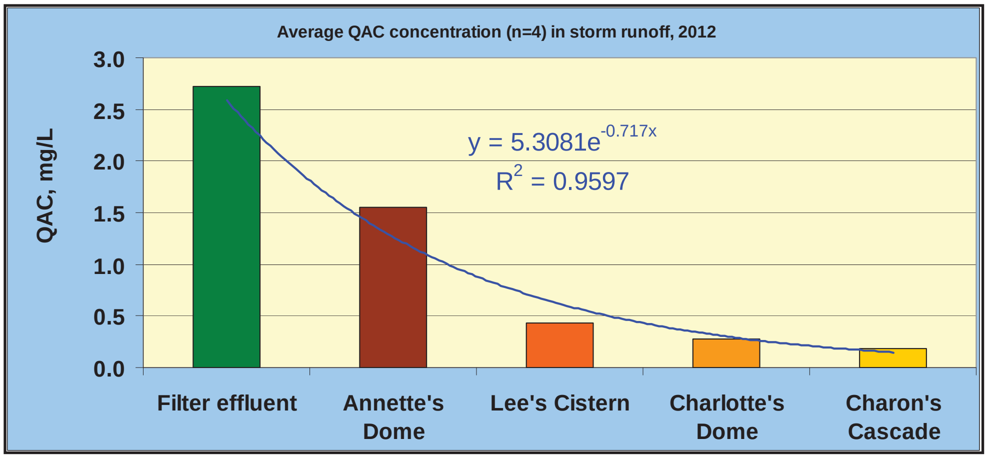

Figure 2: Average QAC concentration along the storm flow path from the Post Office parking lot into the cave system. [bars are average of four rain events in May - September of 2012]

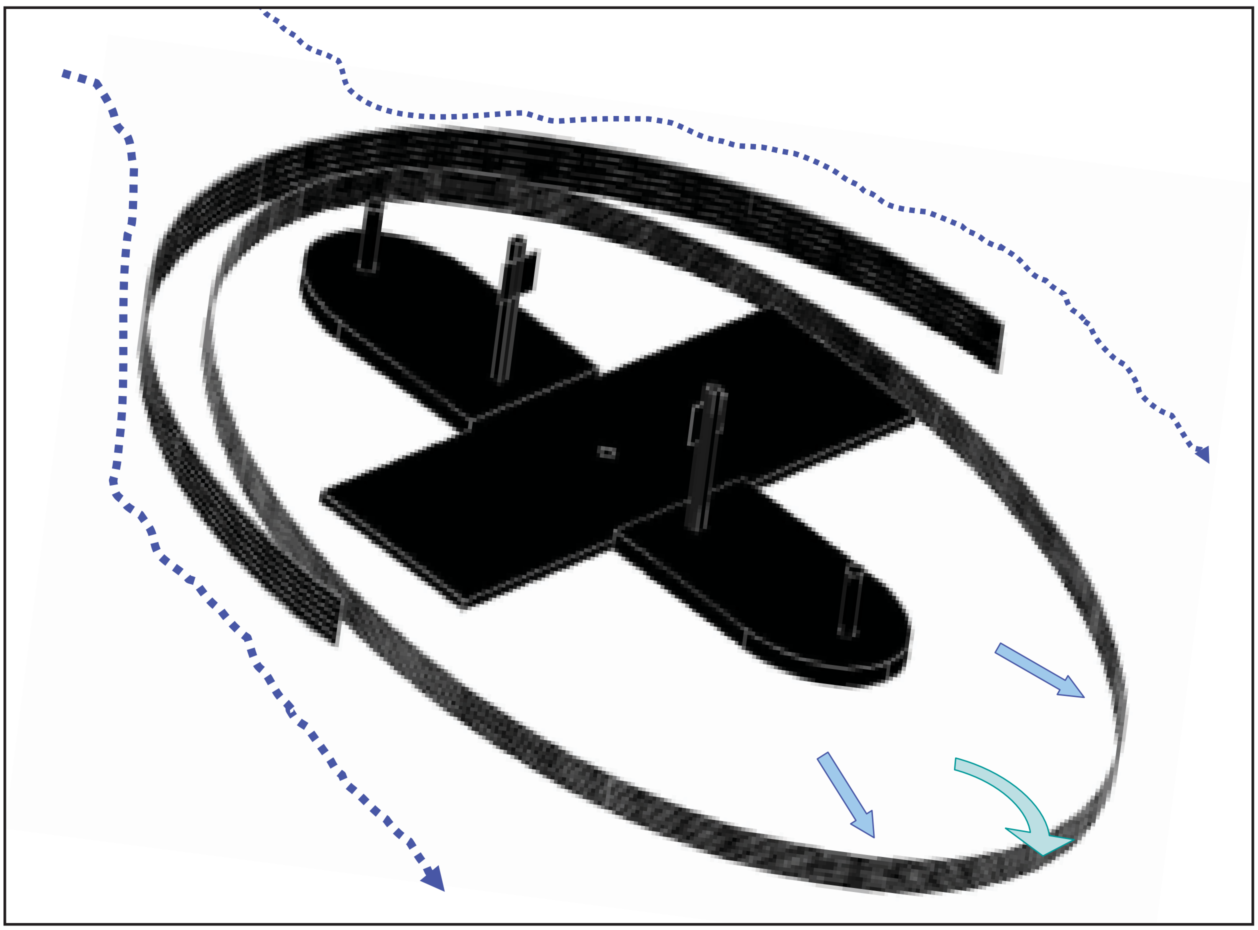

Figure 3: Drawing of the berm and trench system around the RV waste-transfer station to deflect and contain storm runoff. Dimensions of the waste-transfer station, berm and v-trench. Drain slope – moderate, <3%, Trench dimensions average is between 6 inches wide & at most 4 inches deep; Water diversion berm – Height- 2 inches with gentle slopes to avoid jarring bumps for RVs.

the up-gradient section. The small amount of storm water that falls inside the berm will be caught by the v-trench and sent to the sanitary sewer. The berm will minimize the amount of storm runoff that goes into the sanitary sewer. That water will be treated at the wastewater treatment plant since it would contain traces amounts of QAC and gray water from the RV water.

The v-trench would drain to the sanitary sewer. The drain pipe in the center of the waste-transfer station provides the closest connection. This union could be made through a shallow, subsurface pipe connection.

Summary

QACs residue at the RV disposal station are washing into the cave at alarming concentrations. The disposal station drain can be modified at low cost to prevent runoff. It would require a berm to divert runoff from the Post Office parking lot, and, a v-trench to capture any spillage near the dump station. That water captured inside the v-trench will be sent to the sanitary sewer for proper treatment.

Additional acknowledgements

The authors wish to thank Dr. Rick Toomey, III, and Shannon Trimboli, Mammoth Cave International Center for Science and Learning, and the Dr. Dafeng Hui, PI of National Science Foundation-URM grant DBI-0933958 for resources and support.

Spill Retention and Runoff Filtration Structures on Interstate 65 in the Vicinity of Mammoth Cave National Park

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Abstract

In the early 70's, I conducted an ecological study on the Doghill-Donahue Cave System in Southern Indiana. This cave remained relatively un-impacted until Highway 37 was widened near Bedford, and the cave was engineered to be a storm sewer for highway runoff. The consequences of facilitated water entry and easy access for spelunkers via an ungated culvert entrance were severe. Sediments washed into the cave smelled like putrid rubber when disturbed, habitat for cave life was trampled, and beautiful delicate mineral features were smashed. Anticipating that I-65 would someday be widened, I was concerned about possible consequences to Mammoth Cave, and took the following actions to protect aquatic cave life in particular.

In December of 1994, following a meeting with Kentucky Transportation Cabinet (KTC) staff, a letter was written for our Park Superintendent to the KTC. It outlined ecological justifications for retention and filtration structures designed to mitigate pollution from I-65. In 1995 the National Cave Management Symposium was held near Mitchell, Indiana and a field trip showcasing highway runoff filtration structures was led by Senior Ecologist Jim Keith of Earth Tech Environmental Consulting in Bloomington, Indiana. At this same symposium, there was increasing recognition of impacts to cave biota from surface land use of many types (Hobbs 1995). Two years later, hearing from KTC about advancing plans to widen I-65, Jim was invited to Mammoth Cave National Park (MCNP) for discussions with KTC on runoff mitigation structures in May of 1997. To build support for highway runoff retention structures, the South-Central Kentucky Karst was successfully nominated for inclusion on the Karst Waters Institute's global list of the "Ten Most Endangered Karst Communities for 1998."

In June of 1998, a meeting was organized with KTC and Federal Highway Administration staff at MCNP. Agreed upon were basic measures to filter routine runoff and temporarily contain major spills. These were to be low crushed rock check dams originally built as silt checks needed during construction. Basin capacity was to be 10,000 gallons with grass waterways to and through retention basins underlain with geotextile fabric to minimize soil piping. The basins were designed to slowly filter routine runoff while greatly retarding spill entry into the cave aquatic ecosystem. The planned check dams were indicated on I-65 Grade and Drain plans, and were sent to MCNP for review.

Once plans for retention/filtration structures along I-65 were finalized (Figure 1), a paper was jointly written by park and KTC staff for an upcoming National Cave and Karst Management Symposium (Olson and Schaefer 2001). I am glad to report that the first of the retention/filtration structures along I-65 were completed in February of 2011 (Figure 2), seventeen years after the first letter was written to KTC.

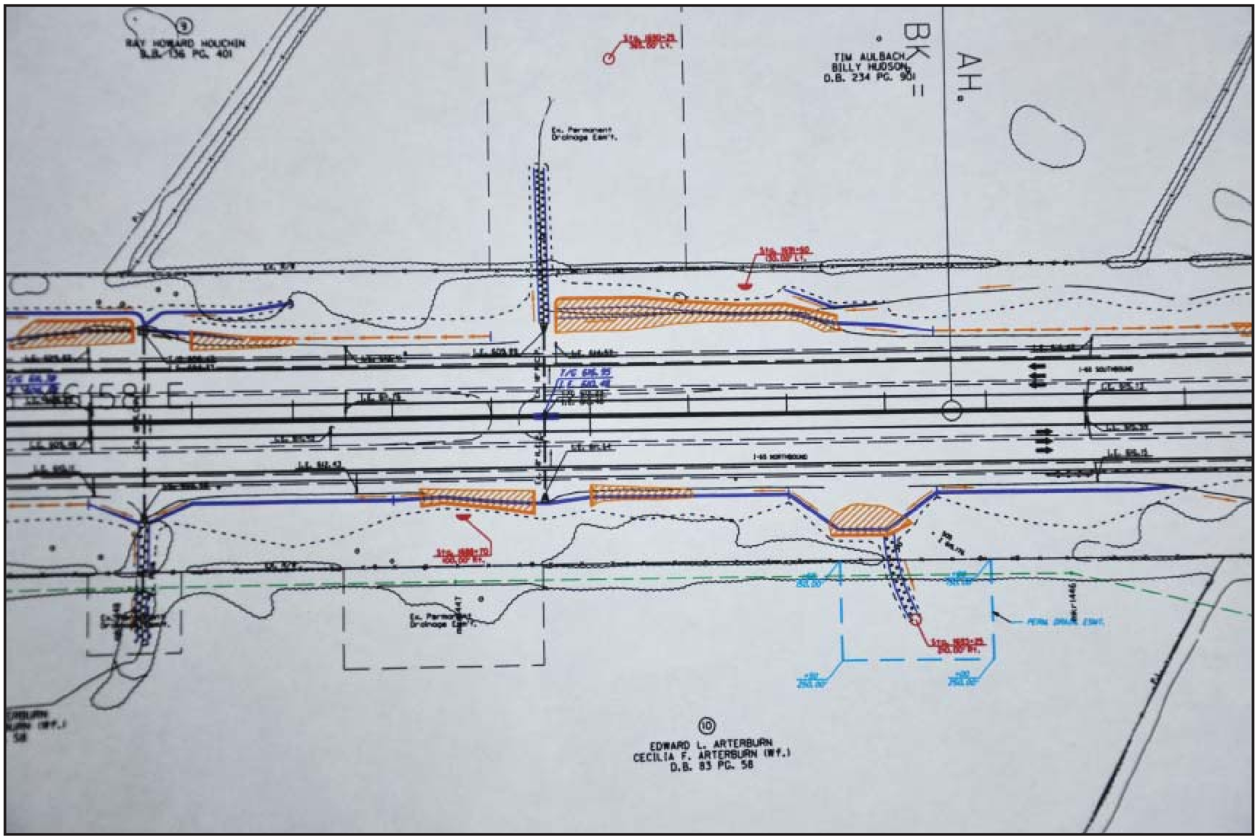

Figure 1: Detail from I-65 drainage plans south of Park City. Planned retention/filtration structures are shown as hachured enclosures.

Figure 2: Photograph of a retention/filtration structure shown in Figure 1

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Mammoth Cave National Park Backcountry Trail and Stream Monitoring, 2009-2012

Larry Johnson[1], Rachel Hawkins[2], Heather Hayes[2], Clare Frederick[2], Kelley Phifer[2], Cathryn Phillabaum[2], Henry Rand[2], Emily Roberge[2], Mary Newton[2], Ana Casillas[2], Michael Unger[2], Michael Luciano[2], Shannon Mathey[2], Emily VanWyk[2]

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Abstract

This project conducted an assessment of backcountry trail conditions on the north side of the Green River in Mammoth Cave National Park during summers of 2009-2012. The project included assessing physical parameters of trails, (width, depth, etc.) and conducting an assessment of water quality of streams in proximity of backcountry trails. The project was conducted by Student Conservation Association resource assistants (12 weeks each) supervised by a natural resource specialist from the Mammoth Cave Division of Science and Resources Management. Trail assessment procedures were based on techniques developed by Jeffery L. Marion, Ph.D, USGS, Virginia Tech (et al.) and previously implemented at Big South Fork NRRA and Hoosier National Forest. These protocols were adjusted by Science and Resources Management staff at Mammoth Cave NP to meet the specific goals this project. (See Marion, J.L. et al. at http://www.pwrc.usgs.gov/prodabs/pubpdfs/6612_Marion.pdf http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5292110.pdf)

This project also conducted an assessment of basic water quality parameters of backcountry streams in proximity of trails to provide supplemental data for the park's larger scale water quality monitoring program. Monitoring of these streams will provide data to detect and track any changes occurring over time which might be related to backcountry trail use, such as increased siltation and/or changes in water chemistry. The project monitored five basic parameters of water quality, including temperature, specific conductance, pH, dissolved oxygen, and rate of flow/discharge. These parameters provide the most basic, yet informative characterization of a stream, and are typically the fundamental components of any monitoring and regulatory program.

In addition to physical and chemical parameters, the project conducted an assessment of biological integrity as an indicator of overall stream health. Bioassessments were conducted by inventorying populations of benthic macroinvertebrates (BMI) present in the waters. (BMIs are animals without backbones which are generally visible with the naked eye.)

The project utilized Streamside Biosurvey protocols redeveloped by the EPA to identify BMI, and sorted these BMI into specific groups that indicated the overall quality of the water. BMI were identified to a broad taxonomic order level (stonefly, mayfly, caddisfly, etc.) and sorted into three general EPA-established groups based on sensitivity or tolerance to pollution/environmental stress; Group 1, Sensitive Species, Group 2, Somewhat Sensitive, and Group 3, Tolerant Species. Higher occurrences of Groups 1 and 2 indicate higher water quality. See website at: http://www.epa.gov/volunteer/stream/vms42.html

Trail Assessment
The project assessed over 207,000 linear feet of trails annually (39.2 miles). All trails assessed are open to hiking and horseback riding. Trails which are also administrative roads and open to official vehicles (i.e. Collie Ridge Trail, White Oak Trail, Buffalo Trail) were not assessed.

The project recorded average length, width, and depth of each trail, and documented the extent of excessive muddiness, excessive erosion, and displaced soil. The project also recorded the number of "unauthorized" or secondary trails present, including shortcuts, cut-arounds, and parallel trails. A brief narrative summary was prepared for each trail and provided to park management. Copies of the Trail Monitoring Manual and the original field data and spreadsheets are on file in the Science and Resources Management office at Mammoth Cave NP.

Results (As of Sept. 2012)
Average tread width: 43.99 inches

Average maximum depth of tread: 2.86 inches

Total soil loss/displacement: 132,202 cubic feet

Total number of secondary trails: 1045

Changes Observed 2009-2012

- As of September, 2012, the total soil loss from all trails assessed, 132,202 cubic feet, would fill a hole more than 100 feet square and 32 feet deep. This would be equivalent to 979 single axle dump-truck loads of soil (5 cubic yards each).
- Of the 39 miles of trail surveyed, overall parameters (trail width, depth, average area) are increasing approximately 4.2% annually. (Total soil loss has increased 17.1% during the 4 year study period.) Several tails sustained notable increases in erosion. Most notably, between the 2011 and 2012 monitoring seasons, Good Springs Trail, west, increased in average width from 50 inches to 64 inches, (+28%) and in average depth from 2.4 to 3.9 inches , (+61%) and in average cross-sectional area from 71 to 195 square inches, (+174%.) During the same time period, Good Springs Trail, east increased from 38% highly eroded to 76.5% highly eroded (greater than 5 inches in average depth).
- The number of secondary, illegal trails has increased from 509 to 1045, an increase of more than 102%.

Backcountry Stream Water Quality/BMI Assessment Results
The BMI surveys indicate that the overall biological integrity/water quality of the backcountry streams in proximity of most trails assessed is excellent. Of the 3 primary streams surveyed, (Wet Prong, Raymer Hollow, and Second Creek), more than 70% of the organisms observed were EPA Group 1, Sensitive Species. Chemical parameters (dissolved oxygen, pH, electrical conductivity, and temperature) also indicate water quality is within normal and acceptable limits at sample points.

The one exception was a major impact area noted where the Mill Branch segment of Good Springs (east) Trail crosses Mill Branch and runoff from the trail enters the stream. The occurrence of EPA Group 1, Sensitive Species was dramatically lower downstream of the crossing, and the percentage of EPA Group 3, Tolerant Species, was significantly higher. This substantial shift is almost certainly due to the runoff/erosion from the Mill Branch trail segment, which is clearly visible throughout the length of the trail. This 2,311 foot trail leads from Good Springs Church down to Mill Branch Road, and receives heavy use from horses. More than 7687 cubic feet of soil has been displaced on this trail, which amounts to an average loss of 3.32 cubic feet of soil per linear foot of trail. (For comparison, a 3 foot wide trail averaging 1-inch deep would lose .25 cubic feet of soil per linear foot; it would take 4 linear feet to displace 1 cubic foot of soil. The average soil loss for the entire 39 miles of surveyed trails in the rest of the backcountry is .64 feet per linear foot.)

Mill Branch, at the immediate bottom of this trail, receives much of this displaced soil, which can be seen on the stream bottom for at least 100 feet downstream of the intersection with the trail. This soil completely covers and replaces the natural rocky substrate of the streambed, thus destroying the habitat for benthic macroinvertebrates. (This trail is scheduled to be closed and rehabilitated as soon as the proposed Big Hollow Trail and Raymer Hollow Extension loop through Maple Springs area is completed, tentatively 2013.)

Overall, the research suggests that erosion and soil loss due to heavy trail use and/or improperly constructed trails can negatively impact biological communities in receiving streams.

White-nose Syndrome at Mammoth Cave National Park: Actions Before and After Its Detection

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[2] Cumberland Piedmont Network, National Park Service
[3] Mammoth Cave National Park, National Park Service

Abstract

Since it was identified in the United States in 2006, white-nose syndrome (WNS) in bats has become an important issue in the management of caves and bats at Mammoth Cave National Park (MACA). The threat of its arrival has led to more intense monitoring of bat populations, increased studies, and interventions with both the visiting public and researchers. The timeline of MACA's WNS response is shown in Table 1.

On January 4, 2013, at the entrance to Long Cave, Steve Thomas and Rick Toomey euthanized and collected a northern long-eared bat (*Myotis septentrionalis*) that showed signs of WNS (white growth on ears, forearms, and wings) (Figure 1). The bat was submitted to the Southeastern Cooperative Wildlife Disease Study where it tested positive for WNS via histopathology and PCR. Eleven other bats were found in the same area as the affected bat (six tri-colored bats, four big brown bats, and one gray bat), but none of them showed any signs of infections. Bats are regularly seen in this entrance area in the winter, so the presence of these bats is not indicative of unusual behavior.

Long Cave is the park's largest hibernaculum. At the 2011 count, it housed approximately 12,000 gray bats, approximately 1,000 Indiana bats, and a few little brown bats, tri-colored bats, and big brown bats. It is a 1.3-mile long cave that is separate from the Mammoth Cave system. It is about 4.5 miles from the Historic

Table 1: MACA's WNS response timeline.

May 2009	Colonial bat roosts closed year-round (except approved WNS and bat research) Decontamination required of incoming gear for researchers
June 2009	Screening of incoming tour visitors and intervention (decontamination, disallowing items, etc).
Feb-Jun 2010	Caves closed signs posted at entrances to 10 park colonial bat roosts
August 2010	Decontamination required between and after cave trips for researchers
January 2011	Park releases WNS Response Plan (plan currently under revision)
April 2011	Tours began post- visit decontamination with walk-over mats containing Lysol solution
Sept 2012	Post tour walk-over mats changed to carpet due to restrictions on Lysol use
Jan 2013	WNS found at Long Cave in MACA

Entrance of Mammoth Cave and about 1.75 miles from the large gray bat hibernacula of Coach and James caves (which house approx. 300,000 gray bats). Gray bats and Indiana bats are federally endangered species.

When WNS arrived in the northeast United States, agencies lacked significant baseline data on healthy bat populations. Beginning in 2009, MACA increased surveillance and monitoring of its bat roosts (both hibernacula and summer roosts) to gather baseline data, detect the arrival of WNS, and to document potential population changes. This monitoring includes biennial hibernation counts, summer emergence counts, and summer acoustic mobile transects. Disease surveillance includes regular entrance checks of bat roosts, targeted winter visits to bat roosts to check for signs of WNS, and cave entrance acoustic monitoring.

MACA's 400,000 visitors a year provide both a great opportunity for education about bats/ WNS and a potential vector for bringing the fungus that causes the disease to the park. To reduce the potential for a visitor to introduce the fungus into the cave, park staff have screened cave visitors since summer 2009. Screening methods include public announcements, pre-tour briefings by guides, and printed posters in the Visitor Center. Visitors are asked if they have been in a cave since 2005. If so, they are asked about whether they are wearing or carrying things that have been in a cave. If they have things that have been in a cave, park staff works with them to reduce the potential for bringing in fungal spores. Measures that can be taken include decontamination, bagging items, or disallowing items from the cave.

Starting in April 2011, when WNS was first identified in Kentucky, MACA began requiring visitors to walk over a decontamination mat after taking walking tours of the cave. This measure was taken to reduce the possibility that MACA visitors could take the fungus away from the cave with them, even if it had not been detected in Mammoth Cave yet. Originally, six-foot-long walkover mats with a Lysol solution were used for decontamination. In September 2012, the park stopped using Lysol solution mats, because their use was deemed to be off-label use. From September 2012 through February 2013, the park has been using twelve-foot lengths of plastic Astroturf –like carpet to physically remove spores from the soles of shoes. The carpet is periodically decontaminated to kill spores that might accumulate on it. MACA is currently working with NPS, EPA, FWS, USDA-FS, and the PHS to identify a decontamination fluid that can be used in the walk-over mats.

All 400+ caves in Mammoth Cave National Park are closed to human access except via ranger-led tours, research permit, or special use permit. People entering caves under research and special use permits are required to decontaminate all gear using current approved national decontamination protocols. They are required to decontaminate gear before going into a park cave, between caves (if they are visiting multiple ones), and before entering any other cave.

Figure 1: Northern long-eared bat from Long Cave that showed signs of WNS.

Symposium sponsored by: the Mammoth Cave International Center for Science and Learning, the Cave Research Foundation, Barren River Imaginative Museum of Science, and the Hoffman Research Institute

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